Southeastern Geology: Volume 18, No. 3
April 1977

Edited by: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY

PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 18 NO. 3 APRIL, 1977

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

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LATERAL STREAM MIGRATION AS EVIDENCE FOR REGIONAL GEOLOGIC STRUCTURES IN THE EASTERN GULF COASTAL PLAIN

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ABSTRACT

Lateral stream migration in southeast Alabama and southwest Georgia has resulted in asymmetrical lateral profiles across streams which do not flow toward the Chattahoochee Embayment. Basinward migration has resulted in steepened southern slopes along streams in this area. This phenomenon seems independent of "cuesta-type" lithic control, faulting, microclimatic variations, or the "Coriolis effect." Regional analysis of subsurface structures and geomorphic trends indicate that a renewal of subsidence in the Chattahoochee Embayment has been responsible both for the southward migration of streams and for the broad but subtle uplift previously termed the "Chattahoochee Arch." The Arch is herein renamed the Chattahoochee Uplift and is redefined to include a large part of southeast Alabama and southwest Georgia.

INTRODUCTION

Several interrelated geomorphic trends are associated with regional uplift in southeast Alabama and southwest Georgia. These trends

(1) Publication approved by State Geologist.

Figure 1. Drainage distribution map. The enclosed area above indicates area influenced by stream migration phenomena.

may be listed as follows: 1) asymmetrical distribution of low order tributaries to the Pea and Conecuh Rivers in southeast Alabama and to the Flint River in Worth, Crisp and Dooly Counties, Georgia; 2) asymmetrical lateral profiles of larger streams; 3) asymmetrical distribution of Pleistocene terraces in southeast Alabama; 4) and the entrenched nature of the Chattahoochee River. The authors believe that this uplifted area is tectonically controlled by adjacent basin subsidence.

Stream migration occurring in the eastern Gulf Coastal Plain was first noted by the authors in Pike and Coffee Counties in southeast Alabama. Evidence of migration has also been found along major streams in other parts of southeast Alabama and in southwest Georgia (Figure 1).

Exposed geologic units in southeast Alabama and southwest Georgia, deposited east of the Mississippi Embayment, range in age from Cretaceous to Holocene with the most complete section occurring along the Chattahoochee River between Alabama and Georgia (Figure 2). The Cretaceous units, predominantly coarse clastics of sedimentary origin, grade laterally westward into carbon facies. However, the Lower Tertiary units, along the Chattahoochee, described by Toulmin and LaMoreaux (1963) are predominantly carbonates. These carbonates

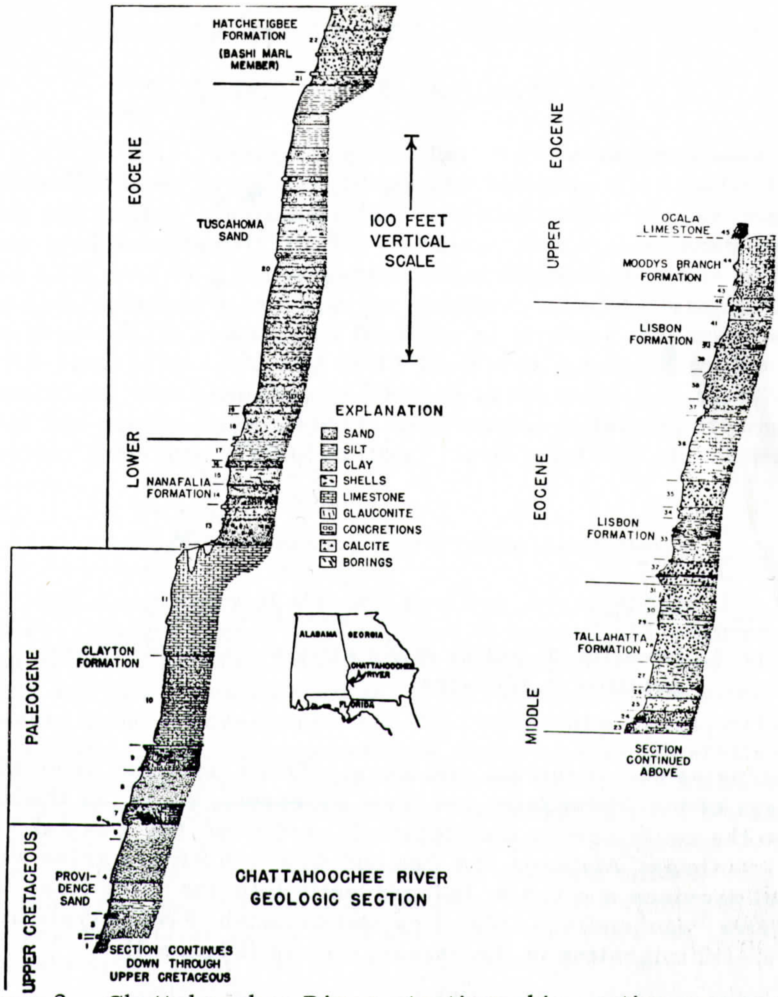


Figure 2. Chattahoochee River stratigraphic section now partially inundated by a series of locks and dams (after Toulmin and LaMoreaux, 1963).

grade laterally into clastics that characterize the Tertiary section of west Alabama and Mississippi. Extensive weathering has resulted in poor surface expression of units in southeast Alabama. In Pike and Coffee Counties, Alabama, the beds strike east-southeast, have a regional dip of 10-35 feet per mile (1.9-6.7 meters per kilometer) to the south and southwest, and range in thickness from 50-150 feet (15.2-45.7 meters) at the outcrop to several hundred feet in the subsurface (Shamburger, 1968; Turner, Scott, and Newton, 1965).

In south Alabama and southwest Georgia the Alabama-Tombigbee-Mobile River system and the Flint-Chattahoochee-Apalachicola River

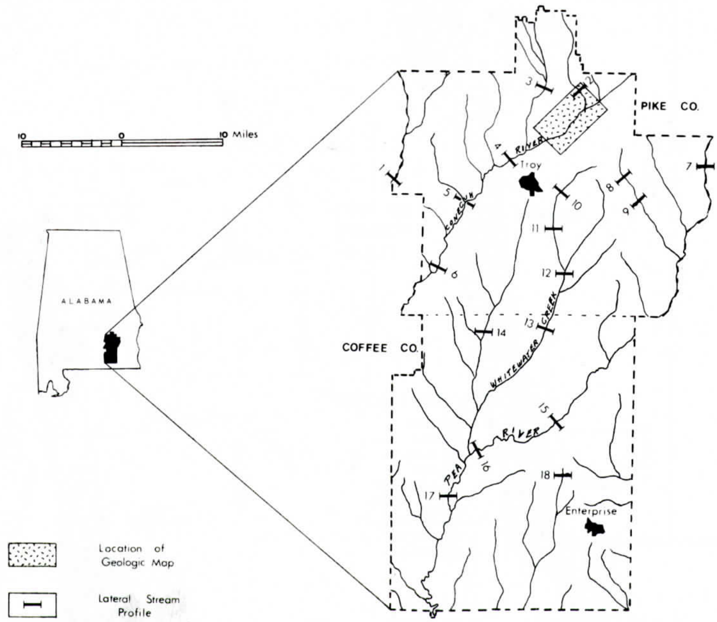


Figure 3. Location of initial study area and lateral stream profiles in Alabama.

system comprise the principal drainage. These systems arise in the outcrop area of the Paleozoic and Pre-Paleozoic rocks in the north and flow to the south across the regional strike of the Coastal Plain units. In southeast Alabama the Pea and Conecuh Rivers arise within the Coastal province and drain independently into the Santa Rosa area of the Florida "panhandle". The Pea and Conecuh Rivers typically illustrate lateral migration of the stream course (Figure 3).

Acknowledgments

The authors wish to thank the following: E. H. Ward of Troy State University for first mentioning to the authors the asymmetry of valley profiles in the Pike County, Alabama, area; Troy State University for funds for research materials and manuscript preparation; the library and publication staff of the Florida Bureau of Geology; staff members of the Geological Survey of Alabama library; and for critically reading the manuscript: Mike Keener and Paul Moser, Geological Survey of Alabama, W. Gary Hooks and Douglas E. Jones, the University of Alabama, Lyman D. Toulmin, Florida State University, and Wakefield Dort, Jr., University of Kansas.

ASYMMETRICAL LATERAL PROFILES AS EVIDENCE FOR STREAM MIGRATION

All of the larger streams of the Pike and Coffee County area in southeast Alabama are characterized by features attributable to lateral stream migration. Asymmetrical lateral profiles across east-southeast or west-southwest flowing streams are typical examples (see Figure 3, 4, and 6). In these cases the steepest slope is consistently on the southernmost side while the northern side is characterized by a gentle gradient. In streams or portions of streams that trend essentially north-south (Figures 3 and 5) the profile is symmetrical but becomes asymmetrical with changes of direction to the east or west. The authors believe that profile asymmetry is attributable to lateral stream migration rather than homoclinal shifting, fault control, or microclimatic variation.

Possible Reasons For Profile Asymmetry

The asymmetry of stream profiles in southeast Alabama and southwest Georgia cannot be attributed to homoclinal shifting and the cutting action of streams downdip into younger units. When these younger units are more resistant than those upon which the stream flows, the result is the succession of cuestas which are characteristic of a belted coastal plain. Representative streams that illustrate this type of asymmetry are Bashi Creek in Clarke County, Alabama, and Big Sandy Creek just south of Tuscaloosa, Alabama. In the Pike and Coffee County area, however, the major streams seem unaffected by the slight changes in lithology that characterize the geologic units of this region. Also, the principal rivers, the Pea and Conecuh, trend perpendicular to the regional strike of the beds and would therefore be little affected by "cuesta-type" lithic control or homoclinal shifting.

Fault control was also considered as a possible agent causing profile asymmetry. However, the streams in this area show no evidence of linear control and display profile asymmetry with a number of different orientations. Also, in their study of the geologic units of southeast Alabama the authors have encountered no major fault zones.

Asymmetrical lateral profiles may also be developed as a result of microclimatic differences caused by unequal sunlight exposure on northern and southern slopes. Evidence for this type of slope control was presented by Hack and Goodlet (1960) and was summarized by Leopold, Wolman, and Miller (1964). The effects of this process in the Gulf Coastal area of the Northern Hemisphere would be essentially the same as those of basinward migration, namely the greater steepness of the southernmost bank. There are, however, several reasons for eliminating microclimatic control as the cause for profile asymmetry. Thornbury (1969) states that south and southeast facing slopes

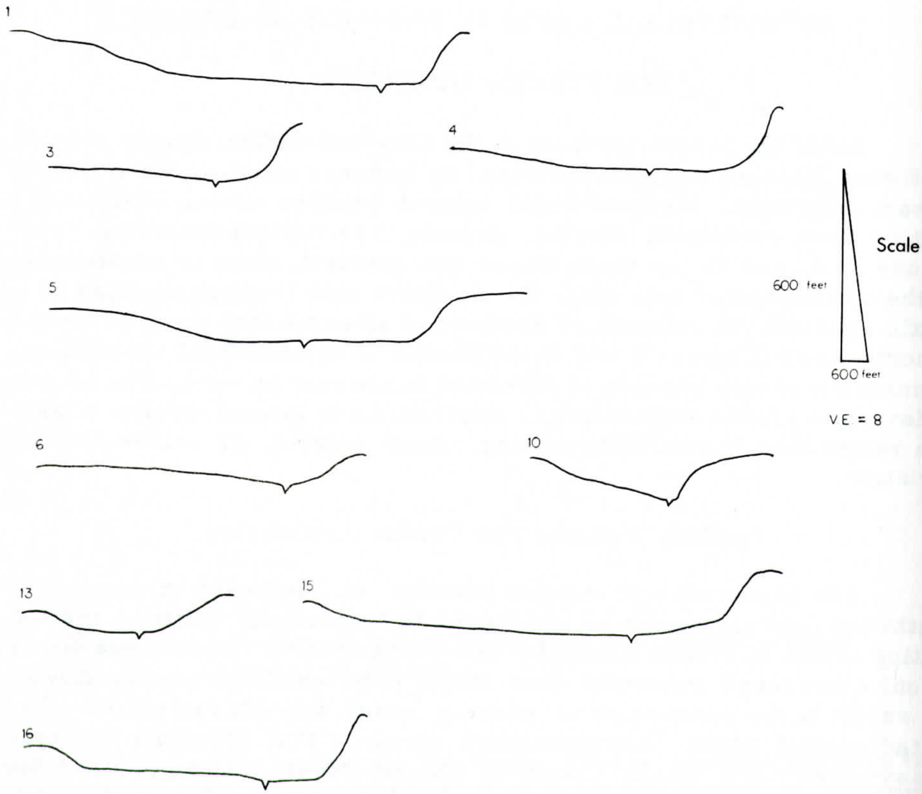


Figure 4. Lateral profiles across southwest trending streams. See index map, Figure 3, for location.

are warmer and dryer with this condition resulting in lesser vegetative covering. Decreases in vegetation result in increased overland flow thereby eroding the slope and causing a gentle gradient. North facing slopes would have thicker vegetal coverings, causing lesser degrees of erosion, and would be steeply inclined. This resulting profile asymmetry would be ubiquitous to the region and would not depend upon the size of the stream occupying the corresponding valley. However, east-west trending valleys of minor streams, not affected by stream migration, show no pronounced basinward asymmetry. This lack of asymmetry is contrary to what would be expected in an area controlled by microclimatic variations. Also, no differences in vegetal thickness for north and south facing slopes were noted along minor stream valleys in Pike County, Alabama (R. A. Dietz, personal communication, 1975).

Streams in southwest Alabama and central Georgia, outside the study area, were also surveyed by use of topographic and geologic maps. In southwest Alabama asymmetrical profiles correspond to

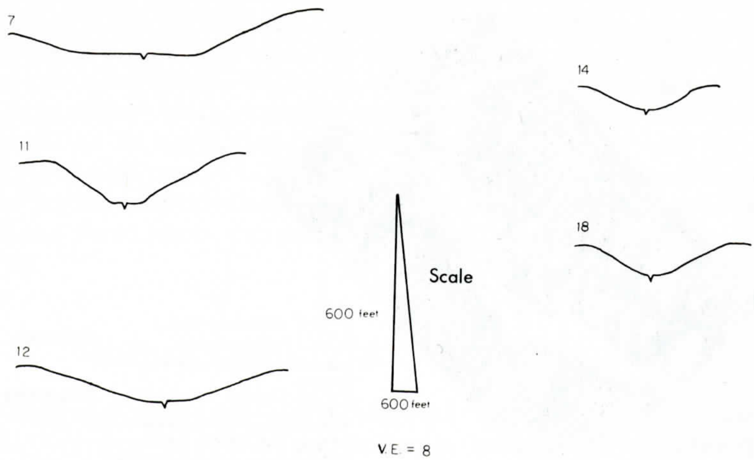


Figure 5. Lateral profiles across north-south trending streams. See index map, Figure 3, for location.

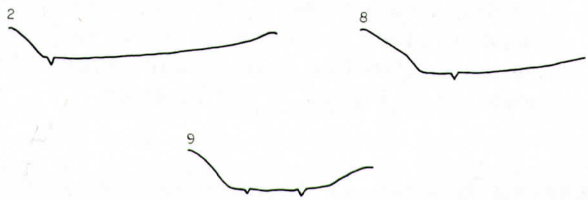


Figure 6. Lateral profiles across southeast trending streams. See index map, Figure 3, for location. Same scale as preceeding.

cuesta development or homoclinal shifting. Otherwise, the streams in this area showed no pronounced asymmetry. Outside the study area in central Georgia no asymmetry was noted. This map survey was incomplete due to poor topographic coverage. The lack of pronounced asymmetry outside the study area also tends to eliminate microclimatic control, which should be evidenced throughout the entire region, as the major cause for valley asymmetry. One would not expect that a humid area exposed to little winter freezing and thawing would be as susceptible to microclimatic differences as more northerly regions.

The authors consider more tenable the idea that asymmetric profiles are the result of large scale lateral migration of the streams. These streams have apprently shifted southward toward the coast in response to changes in "local" base level, namely subsidence in the Chattahoochee Embayment and accompanying uplift along the Chattahoochee Uplift. That the asymmetrical lateral profiles are indeed the

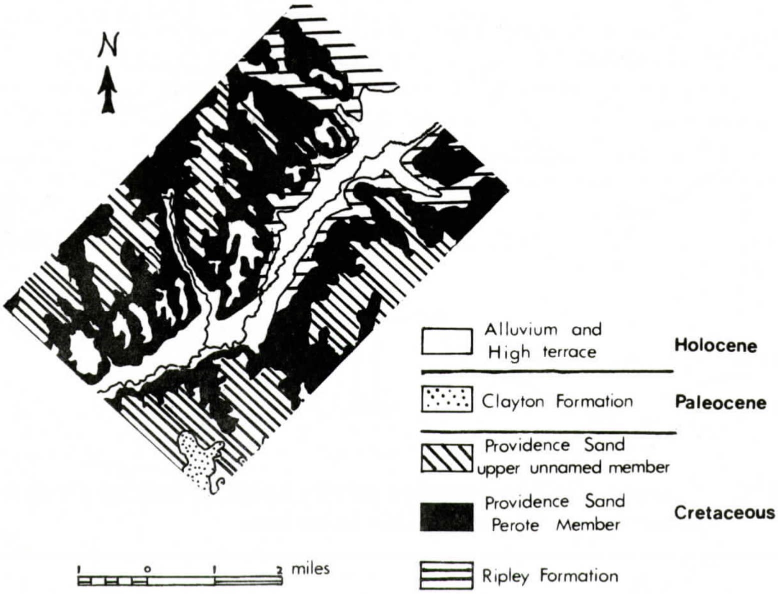


Figure 7. Geologic map showing asymmetrical terrace distribution along the Conecuh River in Pike County, Alabama (Modified from Shamburger, 1968). See index map, Figure 3, for location.

result of basinward migration of streams is supported by the corresponding asymmetry of Pleistocene fluvial terrace deposits laid down adjacent to larger streams in the initial study area.

ASYMMETRICAL TERRACES AS EVIDENCE FOR STREAM MIGRATION

The geologic map (Figure 7) illustrates asymmetrical terrace development on the Conecuh River in Pike County. In Pike and Coffee Counties extensive terraces are consistently developed on the northern gentle slope of the southeast, southwest, or east-west trending streams, while the steeper southern slope shows little or no terracing. South flowing streams exhibit paired terraces, as might be expected from their symmetrical profiles. Terrace deposits are poorly exposed in the region and are generally present as a thin veneer of sand and gravel on the broad, level terrace plain.

The asymmetrical distribution of terraces along streams in Pike and Coffee Counties may be due to the migration of streams before (depositional model) or after (post-depositional model) Pleistocene deposition. If the depositional model is correct, the asymmetry of terrace deposits would be the result of Pleistocene overbank deposition on a gentle northern slope, while the steeper southern slope suffered little or no alluviation. This model would require that asymmetrical lateral valley profiles be developed before or during Pleistocene time. If the post-depositional model is correct, the extensive occurrence of alluvial terraces on the northernmost bank would indicate abandoned Pleistocene channel and flood plain deposits left as the larger streams migrated to the south.

POSSIBLE CAUSES FOR LATERAL MIGRATION

Having considered asymmetrical stream profiles and asymmetrical terrace deposits as evidence substantiating lateral stream migration, it is necessary to discuss possible causes for the migration. The Coriolis effect and basin subsidence will be considered.

Coriolis Effect

Rotation of the earth produces the Coriolis force which is manifested in the Northern Hemisphere by the tendency of moving objects or fluids to be deflected to the right (Gilbert, 1884; Strahler, 1969). Therefore, south flowing streams whose courses are influenced by the Coriolis force would have a tendency toward westward migration. This "force" has resulted in westward migration of streams in the Tombigbee-Alabama-Mobile River system. According to Monroe (1941, p. 43 and 44), the Alabama River in Lowndes and Dallas Counties flows southwest, and migration due to the Coriolis force results in a steepened northwest stream bank. Streams in Pike and Coffee Counties flowing southwest have steeply sloping southeast banks and terraced and gently sloping northwest banks. This cannot be ascribed to westward lateral migration due to the effects of the Coriolis force but demonstrates instead a south-southeastward migration.

Regional Uplift in Response to Basin Subsidence

Attempts to extend the geographic extent of the basinward migration are limited by the incomplete nature of topographic and geologic mapping in the Coastal Plain of Alabama and Georgia. The trend has, however, been noticed as far east as west-central Georgia (Figure 8) and to the southwest as far as Escambia County, Alabama. Similar drainage and profile characteristics in northwest Florida as reported by Marsh (1966, p. 5) may possibly be attributed to the same causes. There is a close correlation between the geographic extent of stream migration phenomena and the area previously mapped as the Chattahoochee "anticline" by Veatch and Stephenson (1911).

Figure 8. Lateral stream profiles in Georgia:

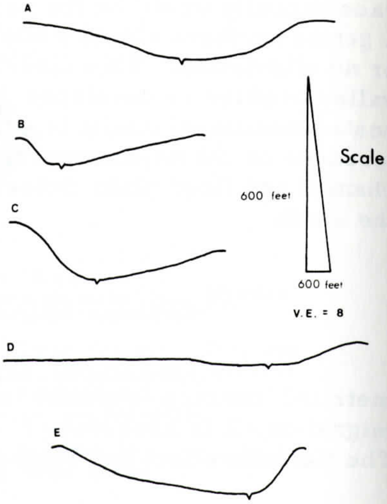
A. Profile across north-south trending Whitewater Creek, Ideal South Quadrangle, Georgia.

B. Profile across southeast flowing Whitewater Creek, Ideal North Quadrangle, Georgia.

C. Profile across southeast flowing Whitewater Creek, Ideal South Quadrangle, Georgia.

D. Profile across southwest flowing Hogcrawl Creek, Byromville Quadrangle, Georgia.

E. Profile across northeast flowing Buck Creek, Ideal South Quadrangle, Georgia.



The Chattahoochee anticline was first proposed by Veatch and Stephenson (1911) as an explanation for drainage pecularities in southwest Georgia. The principal evidence presented for the anticline was the entrenched Chattahoochee River and the general drainage direction in the area.

> A glance at the map reveals a striking inequality in the drainage divides of the two rivers. The tributaries of the Flint are much longer, notwithstanding that the Chattahoochee is much the larger stream. The interpretation of this is that the Flint River tributaries have been accentuated by the slope of the eastern limb of an anticline, whereas the Chattahoochee tributaries have developed under the adverse conditions present on the crest of an anticline. That there have been greater upward earth movements along the Chattahoochee than along the other rivers, is indicated by the much greater depth of the Chattahoochee valley, and the deep trench like channels which the main river and its tributaries have cut in the latest Pleistocene plain. The depth to which the river has cut into this late plain is 40 to 60 feet, while other large rivers have cut into it not more than 15 to 40 feet. The river is probably at present engaged in downward cutting since little or no flood-plain is developed along its course. (Veatch and Stephenson, 1911).

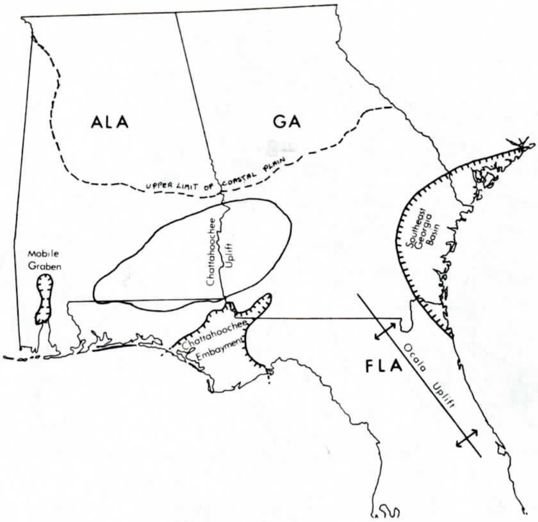


Figure 9. Map showing location of major structural features in the study area of the eastern Gulf region.

Geologic evidence, however, does not support a structural "anticline" in the Chattahoochee area. Anticlinal development of this magnitude would be associated with regional reversals of dip which do not exist. Arguments for and against the existence of the anticline have been presented by Patterson and Herrick (1971). They concluded (p. 14) that "the original proposal of the existence of this anticline by Veatch and Stephenson (1911) and the redefinition by Sever (1965) should be considered invalid."

The geomorphic evidence noted by Veatch and Stephenson and by the present authors could, however, be indicative of a relatively broad uplifted area in the vicinity of the Chattahoochee River. This would not require intensive folding and deformation as in the case of anticlinal structures. This uplifted area, previously designated the "Chattahoochee Arch" by Murray (1961), is herein renamed the Chattahoochee Uplift and is redefined to encompass the area of stream migration phenomena outlined in Figures 1 and 9. The terms arch and anticline are a misnomer, implying a folded structure for which there is no evidence. Figures 1 and 9 also illustrate the proximity of the uplift to a negative structural area known as the Chattahoochee Embayment (Johnson, 1891).

The Chattahoochee Embayment, also known as the Apalachicola Embayment or Southwest Georgia Basin (Murray, 1961) is situated in southwest Georgia and northwest Florida. The basin narrows in southern Georgia and in northern Florida where it is known as the "Gulf Trough" (Herrick and Vorhis, 1963), or the "Suwannee Strait" (Rainwater, 1956; Chen, 1965). Structure-contour and thickness distribution

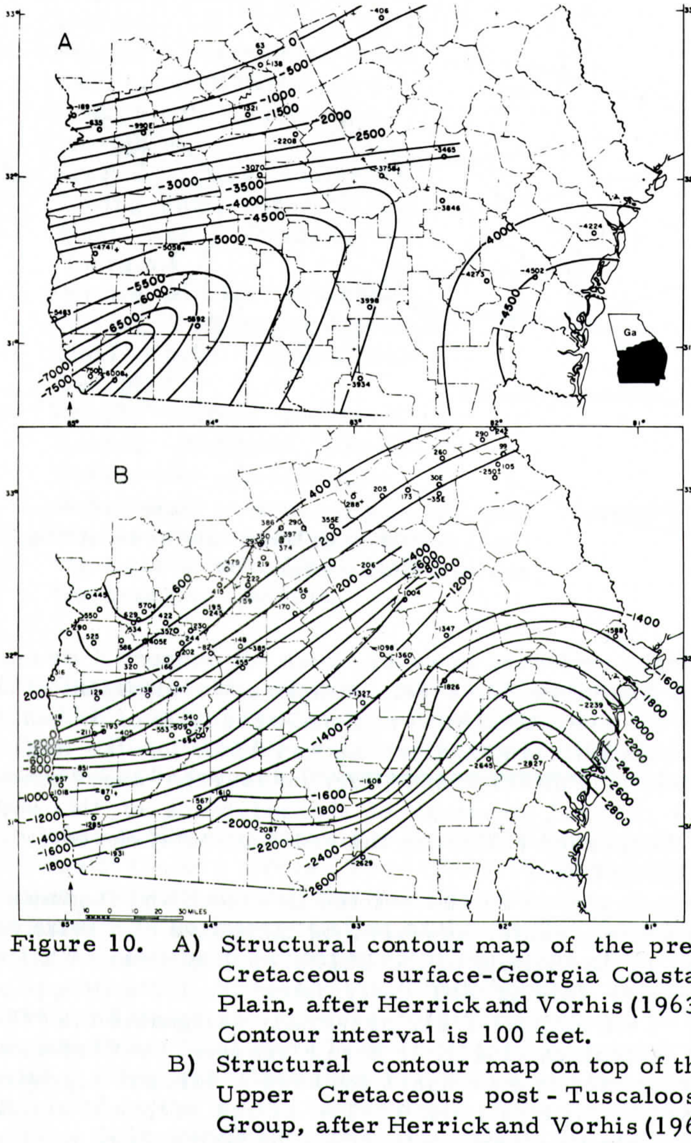


Figure 10. A) Structural contour map of the pre-Cretaceous surface-Georgia Coastal Plain, after Herrick and Vorhis (1963). Contour interval is 100 feet.

B) Structural contour map on top of the Upper Cretaceous post - Tuscaloosa Group, after Herrick and Vorhis (1963). Contour interval is 100 feet.

maps of the Georgia Coastal Plain (Figures 10, 11, and 12) indicate that basin subsidence was occurring during pre-Cretaceous time and continued to Middle and Late Tertiary time. Sediment thickening of a magnitude in excess of 1000 feet (304. 8 meters) and for a duration of time from pre-Cretaceous to Late Tertiary, as shown by the thickness-distribution maps, would only be expected in a subsiding basin. According to Chen (1965), the subsiding trough during Late Cretaceous and

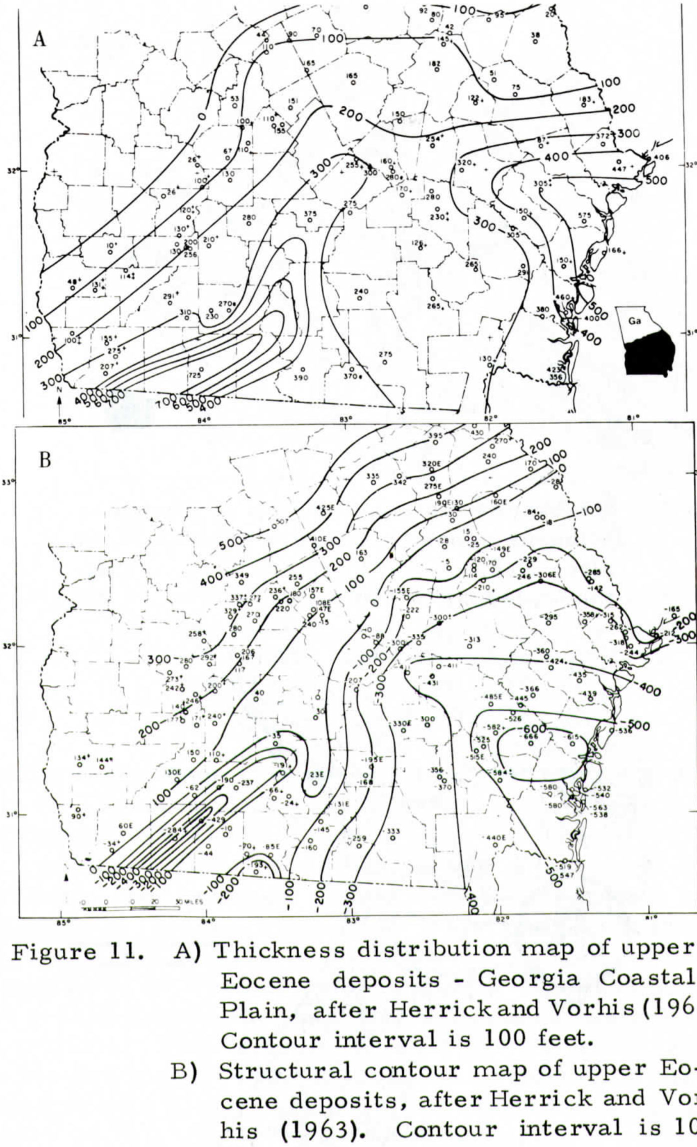


Figure 11. A) Thickness distribution map of upper Eocene deposits - Georgia Coastal Plain, after Herrick and Vorhis (1963). Contour interval is 100 feet.

B) Structural contour map of upper Eocene deposits, after Herrick and Vorhis (1963). Contour interval is 100 feet.

Early Tertiary time was located in north-central Florida and extended northeastward into southeast Georgia. The trough migrated westward during Eocene to Miocene time to the locations illustrated by Figures 11 and 12. After Miocene time, however, the trough, no longer a negative area below sea level, ceased to be a major center of deposition.

Subsidence associated with basement activity is indicated by

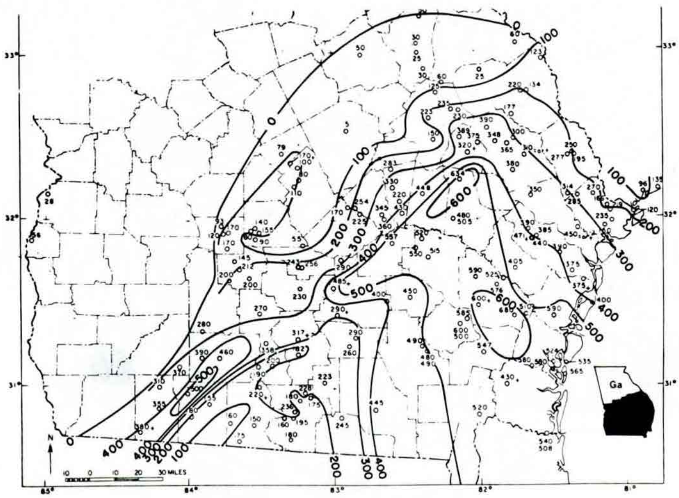


Figure 12. Thickness distribution map of Recent to Miocene deposits-Georgia Coastal Plain, after Herrick and Vorhis (1963). Contour interval is 100 feet.

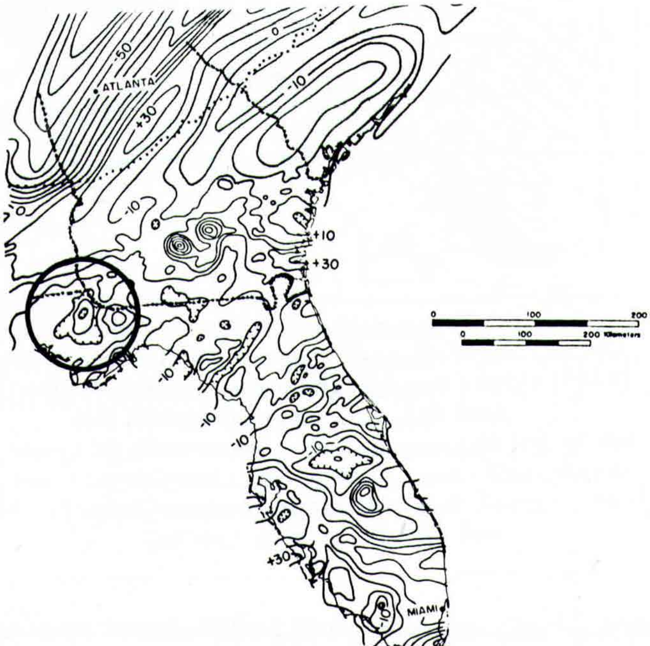


Figure 13. Regional gravity (Bouguer anomaly) map modified from Murray (1961). Circled area shows negative gravity anomaly in study area. Contour interval is 10 milligals.

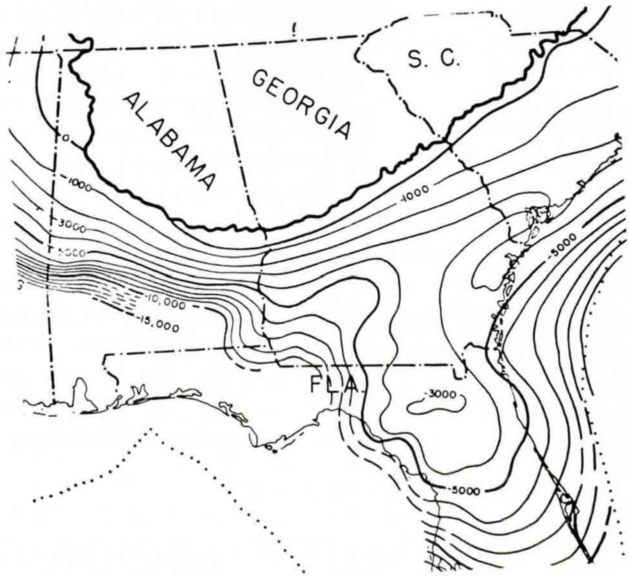


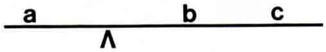
Figure 14. Structural contour map (contour interval is 1000 feet) on pre-Cretaceous basement, modified from Murray (1961).

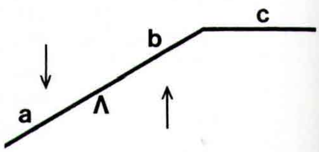
the regional gravity map (Figure 13) which shows a negative gravity anomaly in the Apalachicola area. A similar anomaly is indicated by Chaki and Oglesby (1972) and Oglesby, Ball, and Chaki (1973). Tanner (1966) has proposed that the Chattahoochee Embayment is a down-faulted graben. The basement contour map (Figure 14) can support either a flexure or graben model, but does seem to affirm basement control.

Regardless of whether one considers the subsidence to be of flexure or graben origin, the fact that subsidence has indeed occurred seems irrefutable. This seems contrary to Patterson and Herrick (1971, p. 14) who suggest that the Gulf Trough portion of the basin is a solution feature or a filled marine valley. However, the subsurface maps (Figure 10, 11, and 12) show that subsidence was occurring in the Late Mesozoic and also throughout the Late Tertiary. This prolonged accumulation of sediments would be indicative of basin subsidence and would not be expected in either a solution valley or erosional strait. Furthermore, basement contour maps and regional gravity maps both support a tectonic basement origin for the Chattahoochee Embayment and its northeastern extent, the Gulf Trough.

The Chattahoochee Uplift is interpreted by the authors as a gentle structural upwarping which accompanied subsidence in the area of the Chattahoochee Embayment. This upwarp/downwarp relationship is in

Figure 15. Cross-sectional diagram showing isostatic equilibrium according to Fisk (prior to upwarp/ downwarp).





Cross-sectional diagram showing isostatic equilibrium according to Fisk (after upwarp/ downwarp). Vertically exaggerated.

accord with the principle of isostasy (Figure 15) as applied to the Gulf Coastal Plain by Fisk (1944). Therefore, the broad structural upwarping with no major dip reversals does not have an axis as in the case of an anticline. The different postulated explanations for this structural feature are illustrated by Patterson and Herrick (1971, p. 4) and exemplify the problem of properly delineating the uplift. Since large variations in dip do not occur, the authors feel this subtle structure is best delineated by geomorphic analysis. Extensive weathering, expected in areas of regional uplift, is evidenced by the aerial extent of undifferentiated residuum mapped in counties of southeast Alabama (see Turner and others, 1965; Scott, 1966; Causey and others, 1967; Newton, 1968; and Turner and Scott, 1968). The entrenching of the Chattahoochee River and the lateral migration of surrounding streams resulted from renewal of Basin subsidence, and warping along the Chattahoochee Uplift during Pleistocene and Holocene times. During a lull in basin subsidence, probably during Pliocene-Pleistocene time, the Pea and Conecuh Rivers achieved their present southwesterly course. Their initial drainage direction was probably controlled by adjacent subsidence in the north-central Gulf region. If the Chattahoochee Embayment had been actively subsiding at this time, the Pea and Conecuh would probably have flowed toward this basin. Subsequent Pleistocene and Holocene subsidence in this basin has resulted in southward migration of the older streams as control on the direction of stream flow shifted to the Chattahoochee Embayment.

Smaller streams of Holocene age, which occur as tributaries to the aforementioned major streams, developed during the time of control by renewed subsidence in the Chattahoochee Embayment. The majority of these tributary streams occur on the northern side of the major streams and flow in a generally southern direction, down the slope of the regional uplift. Many of these also demonstrate the effects of basin subsidence by lateral migration. The few tributaries which flow northward, up the slope of the regional uplift, enter on the steep southernmost side of the stream and are predominantly short and entrenched (see Figure 1).

CONCLUSIONS

Asymmetrical stream profiles and asymmetrical terrace distribution tend to substantiate lateral stream migration in the eastern Gulf Coastal Plain. Neither of these characteristics can be fully explained by fault control, homoclinal shifting, or microclimatic variation. Subsidence in the Chattahoochee Embayment and adjacent warping along the Chattahoochee Uplift are invoked to explain several regional geomorphic phenomena including entrenchment of the Chattahoochee River and asymmetry of terracing, lateral profiles and tributary drainage.

The economic value of such a regional geomorphic study is yet to be determined. Areas of potential economic importance include more predictable location and mapping of sand and gravel deposits of Pleistocene age associated with lateral migration of the stream course. Regional land use planning and environmental studies should also benefit from a knowledge of the cause and extent of gulley development along steepened stream slopes in the Pike and Coffee County area.

Most importantly, the present study illustrates the value of a regional geomorphic study in the location and delineation of subtle but extensive structural features. This type of study, but of a lesser magnitude, has been discussed by Thornbury (1969) and has proven to be a useful tool in the location of potential petroleum reservoirs. The present study represents, in part, a regional extension of local phenomena noted by Veatch and Stephenson in their early studies of the Georgia Coastal Plain.

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THE CHATTAHOOCHEE EMBAYMENT

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ABSTRACT

The Chattahoochee Embayment is a major structural feature of northwest Florida and southwest Georgia. It is a broad, shallow syncline with an axis that trends northeasterly and plunges gently to the southwest. The feature was described originally by Johnson (1891). Many subsequent authors have ignored Johnson's work and have proposed at least nine different proper names for the feature. The geology of the embayment is discussed briefly and the literature is reviewed. It is concluded that Johnson's original name "Chattahoochee Embayment" is a correct term, has priority, and should be used hereafter.

INTRODUCTION

In researching the literature preparatory to a study of the subsurface geology of Gadsden County, Florida, it was discovered that at least nine different proper names have been applied to the major tectonic feature of the region. Centered in Gadsden County, there occurs a broad, shallow, structural trough that plunges gently to the southwest. The structure is illustrated by a structure-contour map drawn on the top of the Vicksburg Stage (Figure 1). This trough has been described many times by many authors (Table 1) yet rarely has any previous reference been acknowledged. The result is that the literature is cluttered with numerous names, all referring to the same geologic feature. It is the purpose of this paper to clarify the situation by (1) describing the feature, (2) recounting the historical references to the feature as found in the literature, and (3) suggesting that the name originally proposed by L. C. Johnson in 1891 be used hereafter: the Chattahoochee Embayment.

The Chattahoochee Embayment is a significant geologic feature from an economic and hydrogeologic viewpoint. All of the attapulgite (palygorskite) mines of southwest Georgia and adjacent Florida are located along the present-day axis of the embayment (Sever, 1964). These mines accounted for about 55 percent of the non-communist world production and 76 percent of the U. S. production in 1973 (U. S. Bureau

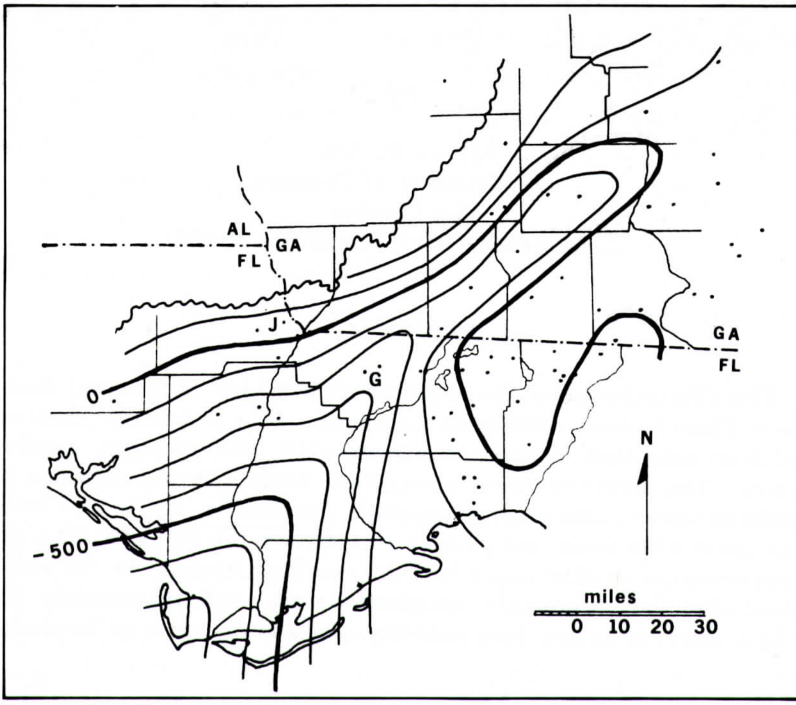

Figure 1. Structural contour map on the top of the Vicksburg Stage (Oligocene) illustrating the general configuration of the Chattahoochee Embayment. Contour interval is 100 feet (msl). Well locations are indicated by the black dots. G is Gadsden County. J is Jackson County.

of Mines, 1975). Along this same trend water wells produce only a fraction of that yielded by wells to the southeast or northwest. Attempts to increase yield by deeper drilling have resulted in very little increase in amount but a large increase in dissolved minerals, making the water unsuitable for most uses. The Chattahoochee Embayment is a unique geologic feature of the southeastern United States that warrants not only more study but a unique geologic name.

GEOLOGIC DESCRIPTION OF THE CHATTAHOOCHEE EMBAYMENT

The embayment, or structural trough, was first described in Panhandle Florida in reference to Miocene time (Johnson, 1891). Later work (Applin and Applin, 1944; Herrick and Vorhis, 1963) has shown

Table 1. Various Proper Names Given the Chattahoochee Embayment as Found in the Literature.

Date	Author	Name
1891	Johnson	Chattahoochee Embayment
1892	Dall and Harris	Suwannee Strait
1893	Foerste	Okefenokee Strait
1955	Toulmin	Apalachicola Embayment
1957	Braunstein	Suwannee River Basin
1961	King	Suwannee Basin
1961	Roberts and Vernon	Southwest Georgia Embayment
1963	Herrick and Vorhis	Gulf Trough of Georgia
1966	Sever	Gulf Trough

that it extends northeastward into south central Georgia. Isopach mapping (May, 1976) reveals that the feature existed at least as far back as early Tertiary time. This mapping is based on water well data, hence can be extended to depths generally less than 300 m (1000 ft.). A few scattered oil tests provide information that it existed in Cretaceous time (Applin and Applin, 1944) and recent deep drilling in Florida shows that the embayment existed in the southern part during Jurassic time (Applegate, Pers. Comm., 1976).

The axis of the embayment trends northeast and plunges gently to the southwest in Florida (Figure 1). Farther northeast in Georgia the axis becomes more nearly horizontal. Isopach mapping shows the location of the depositional centers during specific time intervals. These axes are elongate to the northeast and appear to have shifted laterally to the northwest through time (Figure 2).

The general character of the geologic formations occurring within the embayment are described below; however, the interested reader is referred to Applin and Applin (1944), Toulmin (1955), Moore (1955), Herrick and Vorhis (1963), Hendry and Sproul (1966), Yon (1966), Banks and Hunter (1973), Arden (1974), and May (1976) for greater detail. Basement can be considered to include Triassic and older rocks that lie beneath an unconformity that is widespread in the southeastern United States and emerges at the Fall Zone. The Paleozoic sequence includes a variety of igneous, metamorphic, and sedimentary rocks typical of the Piedmont. Triassic rocks include red beds and diabase. The first sedimentary rocks known to have been deposited within the embayment are those of Jurassic age occurring in the southern part and consisting of evaporite sequences, followed by clastic rocks. During the interval from Early Cretaceous through Early Eocene time clastic sediments were deposited. These sediments are presumed to have

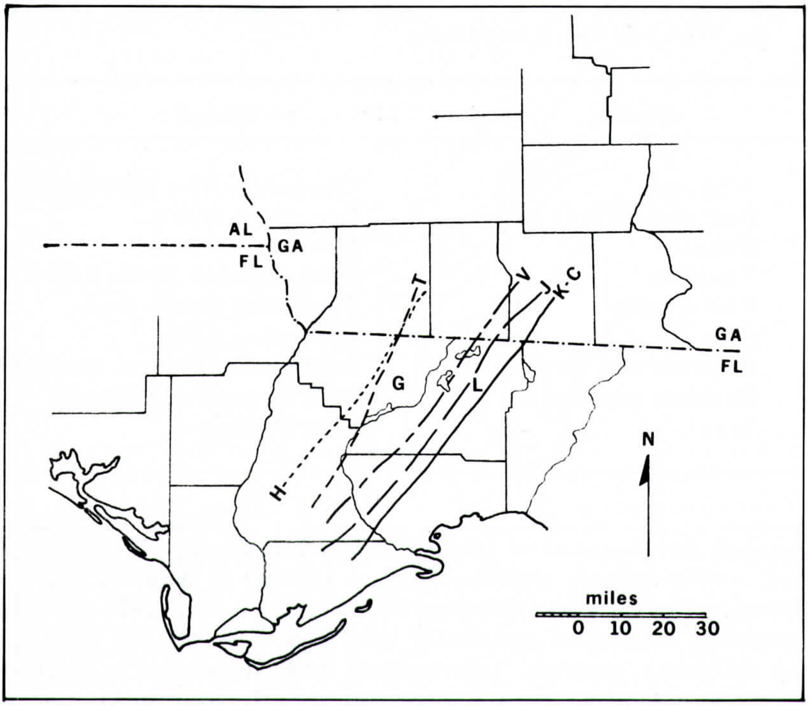

Figure 2. Map showing the position and orientation of depositional axes within the Chattahoochee Embayment as determined by isopach mapping. K-C is Cretaceous-Claiborne. J is Jackson. V is Vicksburg. T is Tampa. H is Post-Tampa. G is Gadsden County. L is Leon County.

been derived from a source to the north, delivered perhaps by an ancestral Chattahoochee River. During this time limestones were being deposited to the southeast on the Florida Platform. The boundary between clastic and carbonate depositional environments lay only 30 to 40 km east of the area shown in Figure 1. Through time this boundary migrated to the northwest. This may have been due to a gradual decrease in the influx of clastic sediments resulting from erosional maturation of the source area. Limestone deposition become dominant in Middle Eocene time and continued through the Oligocene. During Early Miocene time, clastic sediments once again began to be delivered from the north due to renewed uplift in the Appalachian Mountains. The Middle Miocene Hawthorn Formation consists of fine to medium-grained clastic sediments with minor amounts of limestone. The overlying Miccosuckee Formation of Late Miocene or Pliocene age consists of clastic sediments deposited in a deltaic environment. The upper surface of the Hawthorn Formation is essentially horizontal, hence it filled the embayment.

The origin of the embayment is unknown and will probably remain so until additional information (especially geophysical) becomes available. Probably the embayment originally was formed as a tectonic structure in Early Mesozoic time. The maintenance of the embayment in later time could have been due to either tectonic or geomorphic factors. The fact that the axes of the depositional centers shifted to the northwest through time suggests that maintenance of the embayment was due to surface processes rather than deep-seated ones. It may have been a strait separating the mainland from the Florida Platform as suggested by Johnson (1891) and kept open by oceanic currents such as an ancestral Gulf Stream.

An alternative interpretation, which cannot be fully evaluated until much more information becomes available, is that the feature is related to a buried Triassic basin. The orientation and geometry of the trough is reminiscent of the exposed Triassic basins in North Carolina. It lies only 200 km SSW of the recently described Dunbarton Triassic basin which is situated on the Georgia-South Carolina border and buried by a cover of Coastal Plain sediments (Marine and Siple, 1974). Deep wells drilled in the Chattahoochee Embayment region have bottomed in red beds and/or diabase of Triassic age. Two difficulties with this interpretation are (1) that the laterial shift of depo-axes is unexplained and (2) that the basin must have continued to subside through Early Miocene, unlike any known Triassic basin. Additional information from drilling and geophysical survey will allow further evaluation of these interpretations in the future.

REVIEW OF LITERATURE

Lawrence C. Johnson (1891) presented a paper to the Washington meeting of the Geological Society of America entitled "The Chattahoochee Embayment" describing a feature located in north Florida and southwest Georgia. He intimated that the name "Apalachee" was preferable (after the Apalachee Bay and Apalachee Indians of the area), but to avoid any possible conflict with the (misspelled) Appalachian Mountain system to the north (which was also named after the Apalachee Indians (Watts, 1975)) he proposed the name "Chattahoochee Embayment" after the Chattahoochee River (which becomes the Apalachicola River at the Georgia-Florida State Line). He recognized a Miocene embayment reaching from the Gulf of Mexico northeastward to the Atlantic Ocean, bounded on the northwest by a headland located in present day Jackson County and on the southeast by islands composed of Eocene limestones located in the present-day area of the Suwanee River basin.

The following year Dall and Harris (1892) published their Correlation Papers of the Neocene and introduced the name "Suwanee Strait" to describe the same Miocene feature. Dall and Stanley-Brown

(1894) midly chastise Foerste (1893) for introducing the new name "Okefenokee Strait", instead of referencing their (improper) term "Suwanee Strait". In the same paper they referenced Johnson's (1891) work but ignored his prior name "Chattahoochee Embayment".

Stephenson (1928) described a "shallow syncline" separating the "Chattahoochee anf Florida upwarps" but did not name the feature, nor did he refer to Johnson's paper.

Applin and Applin (1944) described a "channel or trough extending southwestward across Georgia through the Tallahassee area of Florida to the Gulf of Mexico". They did not name the feature nor refer to previous descriptions.

Toulmin (1955) referred to the feature as the "Apalachicola Embayment" without note of previous descriptions or references. This name was retained by Puri and Vernon (1964).

Braunstein (1957) discussed his Figure 1 that shows major tectonic elements and lists "... inferred Triassic grabens, the Suwanee Strait, the Suwannee River Basin,... " His figure shows the axis of the "Suwannee Strait", which coincides with that of the Chattahoochee Embayment. It also shows his "Suwannee River Basin" (not to be confused with the present drainage basin of the Suwannee River), a tectonic basin that includes the Chattahoochee Uplift, the Chattahoochee Embayment, the Ocala Uplift, and the Peninsular Arch. The position of the basin boundary is not explained.

King (1961) discussed the "Suwannee River Basin" of Braunstein and shortened the name to "Suwannee Basin" stating that it was "Originally named the Suwannee River Basin by Braunstein... but the shorter term seems adequate and preferable. "

Murray (1961) referenced Johnson (1891) but called the feature the "Apalachicola (Southwest Georgia) Embayment".

Roberts and Vernon (1961) referred to the feature as the "Southwest Georgia Embayment" (with the "Apalachicola Embayment" being shown in their figure as part of the Gulf Coast Geosyncline farther west).

Herrick and Vorhis (1963) formally proposed the name "Gulf Trough of Georgia" for the Georgia portion of the embayment without reference to the fact that a number of different names had been previously used (though they did refer to the Applin's (1944) description) nor to the fact that half of the feature lies within the state of Florida.

Sever (1964) called the feature a "southwest-plunging structural trough", without name. Sever (1965) described the feature as a "downwarp". Sever (1966), however, called the feature the "Gulf Trough" truncating Herrick and Vorhis' (1963) name for the feature. This shortening of the name was unfortunate, as later workers (for example, Banks and Hunter (1973)) have followed Sever's term, which is much too similar to the "Gulf Coast Geosyncline", a wholly distinct structural feature.

Patterson and Herrick (1971) discussed the feature, reviewed some of the literature on the subject, and pointed out the multiplicity of names. They referred to Johnson's (1891) paper, yet persisted in calling the feature the "Apalachicola Embayment", without apparent reason.

CONCLUSION

The literature regarding the Chattahoochee Embayment is presently cluttered with terms and references that are improper. The situation has so deteriorated that even the improper terms are being misused (such as the shortening of "Gulf Trough of Georgia" to simply the "Gulf Trough"). The earliest reference to this structural feature was found to be that of Johnson (1891), which was published in the Bulletin of the Geological Society of America. Since this description was the first and was published in a reputable, widely-circulated geologic journal, the name "Chattahoochee Embayment" clearly has priority. The term is correct and should be used hereafter.

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TRACE METAL GEOCHEMISTRY OF A FLUVIAL SYSTEM IN EASTERN TENNESSEE AFFECTED BY COAL MINING

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ABSTRACT

The concentration, distribution, and mode of occurrence of trace metals in sediment from the New River fluvial system were investigated and delineated. The sampling area was chosen because of its proximity to strip and deep mined highlands. This research produced the first reported data on Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn concentrations in contemporary stream sediments (affected by coal mining) on the Cumberland Plateau of Tennessee.

Trace metals were shown to travel not only as ions attached to sediment but also as cations sorbed onto hydrous metal oxides which may be suspended in stream waters. Iron and Mn were found to be the dominant cations comprising these hydrous oxides. Copper, Pb, and Cr are the only metals which are not closely associated with the hydrated oxides.

The studied trace metals were generally concentrated in the clay and very fine silt-sized sediment fractions. All of the metals, except Cu and Ni, occurred in concentrations much exceeding their respective average sedimentary abundances. It is inferred that Cu and Ni are either scarce in the local strata or preferentially removed from the system.

Preliminary x-ray diffraction examinations of the sediment revealed that the major minerals comprising the samples were quartz,

illite, kaolinite, montmorillonite, and chlorite. Goethite and anglesite were present in minor amounts in some samples.

INTRODUCTION

As a result of strip mining, large amounts of coal and its enclosing strata become exposed to the atmosphere. Weathering liberates a number of trace metals that may be ultimately incorporated in the fluvial system. Once in a fluvial system, these metals may become available to biota, and thus a potential health hazard.

The purpose of this research was to establish trends in the accumulation of trace metals in sediment from a fluvial system that is heavily affected by the surface mining of coal. This study delineated the total concentrations of certain trace metals at each sampling site, and the concentrations of metals within the constituent size fractions from each sample locality. A preliminary determination of the mineralogy of the sediments was accomplished, and a relationship between the presence of certain minerals and elevated metal concentrations has been suggested.

Ebens and Connor (1972) reported average concentrations of certain elements in Carboniferous strata. Since the stream sediment studied here was derived from the weathering of Pennsylvanian outcrops some of the average concentrations reported by the above authors were helpful in understanding the sources of certain trace metals studied in the present research. Ebens and Connor (1972) presented the following data in μ g/g:

Metal	Pennsylvanian Shales	Pennsylvanian Sandstones
Cr	95	33
Cu	23	8.4
Ni	38	19

Certain metal concentrations determined in the present study approximate these values.

Massey and Barnhisel (1972) reported that some metal values in unfiltered interstitial solution in strip-mine spoil banks have the following maxima (in ppm):

Fe	Mn	Zn	Cu	Ni
37,500	1800	145	85	122

These values approximate some of the metal concentrations reported in sediment analyzed in the current study. Thus, spoil bank material could be a major contributor to the heavy metal content of proximal fluvial systems.

Acknowledgments

The authors wish to express gratitude to the National Science Foundation for generous financial assistance during the course of this investigation. Also, the Department of Geological Sciences at the University of Tennessee provided laboratory space and equipment used in the current study.

LOCATION AND METHODS OF SAMPLING

Because of the extensive strip and deep mining of coal in the northern Cumberland Plateau of Tennessee, this area was selected for study. The Indian Fork stream system, a tributary of the New River, and the section of New River directly affected by the addition of material from Indian Fork were the sampling areas. The basins which these streams occupy were completely surrounded by strip mined highlands.

The sampling area is located in the southeast quarter of the Fork Mountain quadrangle, Figure 1. The coordinates of the center of this quadrangle are $84^{o}25''$ west longitude and $36^{o}10''$ north latitude. The area of interest is about 0.4 miles southeast of the junction between Scott, Anderson, and Morgan counties in northeastern Tennessee.

The strata which surround the Indian Fork and New River fluvial systems are predominantly intercalated shales and sandstones with interspersed coal seams (Luther and Avery, 1970). A few thin-bedded limestones have been noticed in the Pennsylvanian sequence of the northern Cumberland Plateau by Kenneth Walker, Department of Geological Sciences, University of Tennessee at Knoxville (1975, personal communication). All of the strata in this area are essentially horizontal.

Sediment samples were taken from stream beds at selected areas of accumulation of sand-size and smaller material. Sediment was removed from these areas by means of random scooping in the stream bed. The sample stations were spaced approximately one-half mile apart as shown in Figure 2.

In sampling, an effort was made to locate sites above and below major tributaries. Thus, determination of any effects that these tributaries have on the metal content of the sediment in the major stream was possible. Four samples (NR1-NR4) were taken from New River (one above and three below its confluence with Indian Fork), and five samples (IFA-IFE) were removed from the Indian Fork system (IFA was taken 0.1 mile upstream from the confluence with New River, while the other samples were taken at 0.5 mile intervals upstream).

A tributary, Joe Branch, which drains part of the basin north of IFB, flows from the vicinity of an abandoned deep mine. The tribuary, Lick Branch, which joins Indian Fork upstream from IFC and IFD, originates primarily as drainage from an auger hole in a coal seam.

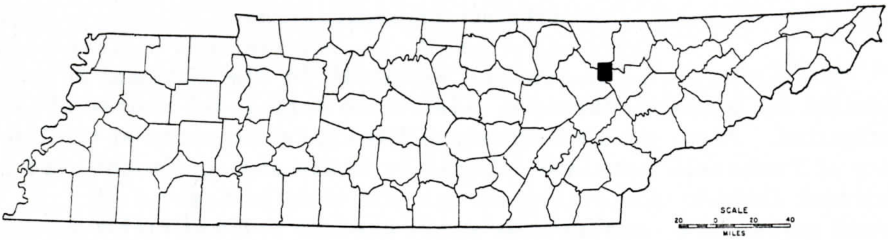

Figure 1. Outline map of Tennessee showing location of Fork Mountain Quadrangle.

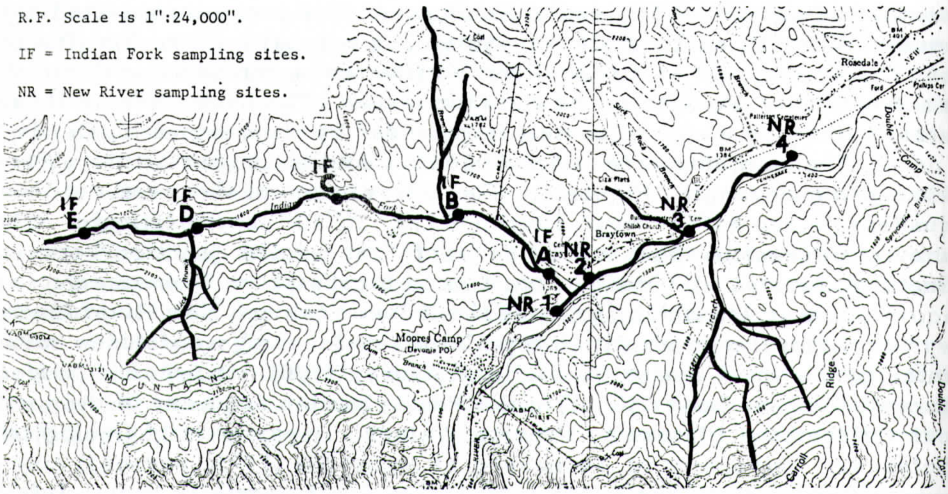

Figure 2. The portion of Fork Mountain Quadrangle which contains the area of sampling.

ANALYTICAL PROCEDURES

One pint (about 500 g dry weight) of grab sample as a suspension was taken at each sampling site and stored in a refrigerator at 2^{o} to $4^{o}C$. Three separate analyses were performed on portions of each sample. The first two analyses were performed on separate portions of the <1 mm sample without dividing the < 1 mm material into constituent size fractions. A third analytical procedure utilized size fractions of a portion of the original sample. Analytical procedures are after Jackson (1958).

In the first procedure, extractions (from 5.00 g of unground < 1 mm sample) of surface-adsorbed metals, and subsequent extraction of metals associated with hydrous oxides were accomplished. The surface adsorbed metals were removed from the sediment by complexing with Na-citrate, a chelating agent. Hydrous Fe oxide affiliated metals were extracted by reduction with Na-dithionite. The reduced metal species were simultaneously chelated with Na-citrate. $NaHCO_3$ was used as a buffering agent to maintain a relatively constant pH during extractions.

The reducing agent, Na-dithionite, was chosen because it does not reduce MnO_2 or $Mn(OH)_2$; however, elevated Mn contents in the extract derived from this reduction reaction indicate that Mn may exist in a compound(s), in which the Mn ion occurs in an oxidation state other than +2 or +4. The metal content of this extract appears to be the sum of those metals affiliated with both Fe and some complex Fe-Mn hydrous oxides.

In the second procedure, about 0.3 g of the < 1 mm sample (which had been ground so as to pass through a 200 mesh sieve) was dissolved in a mixture of perchloric and hydrofluoric acids. Both of the extracts and the solutions derived from acid digestion were analyzed for their metal contents by atomic absorption spectrophotometry.

Finally, individual size ranges of the sediments were analyzed chemically. Size separations of < 1 mm material were carried out by means of sedimentation, sieving, and centrifugation. The resulting size ranges were: 0.2-2μ (coarse clays); 2-5μ (fine silts); 5-53μ (coarse and medium silts; 53-105μ (very fine sands; and 105-1000μ (fine, medium, and coarse sands). These fractions were oven dried at 50°C, weighed, and stored. No material < 0.2μ was separated (or collected) due to the absence of this size of sediment.

About 0.3 g of each resulting size range (ground to pass through a 200 mesh sieve) was acid digested in the same manner as previously described. The resulting solutions were analyzed for metal content by atomic absorption spectrophotometry.

Preliminary identification of the minerals in sediment from Indian Fork and New River was carried out by the use of x-ray diffraction. X-ray diffractograms were obtained from sedimentation mounts of petrographic slides. After obtaining the initial diffractogram the 0.2-2μ and 2-5μ slides were heated to 550°C for 90 minutes for the purpose of rudimentary clay mineral identification. After heat treating the slides were again x-rayed to detect any significant changes in d-spacings or peak heights.

RESULTS AND DISCUSSION OF THE ANALYSES

OF ENTIRE SAMPLE < 1 MM

Table 1 presents the average metal concentrations of all < 1 mm samples from Indian Fork and New River. It is obvious from the data in this table that iron is by far the most abundant metal. Manganese concentrations are about two orders of magnitude lower than those of

Table 1. Metal Concentrations for < 1 mm Samples (in μ g/g) from Acid Dissolutions

	Location	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
	IFE	55	3	33	19	43	41	169	733	36,220
	→	Entry of Lick Branch								
	IFD	44	3	26	20	33	90	168	682	47,620
	IFC	78	3	39	29	41	107	189	897	63,376
	→	Entry of Joe Branch								
	IFB	87	4	39	33	49	130	229	1110	92,339
Downstream	IFA	55	3	32	25	42	82	147	705	45,629
	Averages	64	3.2	34	25	42	90	180	825	57,037
	NR1	66	3	35	25	43	82	194	507	38,731
↓	→	Entry of Indian Fork								
	NR2	87	5	51	31	66	162	715	566	71,551
	NR3	57	4	31	30	42	82	239	700	43,246
	NR4	77	3	36	28	43	54	207	650	42,205
	Averages	72	3.8	38	29	49	95	339	606	48,933

Fe; however, Mn is approximately one to two orders of magnitude more abundant than each of the other metals in the samples.

There is a marked increase in the concentrations of Fe and Mn at sampling sites downstream from the influx of tributaries. Perhaps owing to their higher general abundance, Mn and Fe are the best indicators of tributary influence. Arrows in Table 1 indicate the approximate locations of the tributaries previously mentioned: Lick Branch, Joe Branch, and Indian Fork.

It is evident from examination of Table 1 that Joe Branch affects the metal concentrations in the Indian Fork sediment more than does Lick Branch. The metal levels are much higher directly downstream from the confluence with Joe Branch than they are downstream from Lick Branch's entry into Indian Fork. As previously stated, Joe Branch drains from the vicinity of a deep mine.

The influx of Indian Fork has a much greater effect on the New River sediment than does either of the tributaries (which enter Indian Fork) on the sediment in Indian Fork. Fe and Mn quantities at IFB are an exception to this generalization. The data show that all levels of metals are noticeably higher at NR2, which is directly downstream from Indian Fork's entry, than are the corresponding metal values at NR1, which lies upstream from the confluence.

Table 2. Comparison of Metal Concentrations from Chemical Extracts: Surface Adsorption (S Column) and Adsorption on Hydrous Oxides (H Column) in μ g/g.

Location	Cr		Cd		Co		Cu		Ni		Pb		Zn		Mn		Fe	
	S	H	S	H	S	H	S	H	S	H	S	H	S	H	S	H	S	H
IFE	*	8 6	0.1	1.8	1.4	11.4	0.8	2.9	1.4	9.9	0.8	*	6	#	15	550	172	20,900
IFD	*	8.6	0.1	1.8	1.3	13.4	0.8	4.0	1.1	9.9	2	*	6	#	10	550	260	26,400
IFC	*	9.5	0.12	1.5	1.8	14.3	0.8	4.0	1.7	11	2.4	*	4.8	#	16	660	292	34,100
IFB	*	14.3	0.16	2.6	1.4	14.3	0.9	4.4	1.4	13.2	2.8	*	6	#	10	726	232	46,862
IFA	*	7.7	0.14	1.8	1.7	11	0.8	2.9	2	11	2	*	8.8	#	15	550	240	27,500
NR1	*	7.7	0.14	1.5	2.4	7.2	1.4	2.9	1.9	7.5	3.2	*	8.0	#	8	220	520	23,100
NR2	*	9.5	0.24	2.2	1.6	8.4	1.6	4.0	2.4	8.4	1.2	*	12.5	#	17	264	580	39,600
NR3	*	8.6	0.22	1.8	2.8	7.9	1.4	2.9	3.2	7.9	2	*	8.8	#	20	264	420	30,360
NR4	*	7.7	0.26	1.8	2.3	7.1	1.4	2.9	2.1	7.5	2	*	12.5	#	13	242	440	23,110

* Below Limits of Detection.

#Indeterminable Due to Reagent Contamination.

RESULTS AND DISCUSSION OF THE ANALYSES OF SURFACE ABSORBED AND HYDROUS OXIDE AFFILIATED METALS

The relationships of metals to surface adsorption on sediment and the affiliation of metals with hydrous oxides are useful in understanding the modes of occurrence of cations in the sediment. Table 2 illustrates these relationships. The samples had less than 10 percent of the total amount of each metal associated with surface adsorption. Most of each metal was found to be associated with the hydrous oxides. MnO_2 and $Mn(OH)_2$ were not supposed to be affected by the reducing agent ($Na_2S_2O_4$); however, reduction of other forms of Mn hydrous oxides may account for the high Mn values in this category. Also, a hydrous oxide with both Mn and Fe in cation sites could be the main form in which Mn occurs (Posselt, Anderson and Weber, 1968). Further studies in this area should be able to delineate the mode of Mn occurrence.

Cadium concentrations illustrate the general trend stated above. Four percent of the total Cd is present in the surface adsorbed group; 63 percent of the Total Cd is present in the hydrous oxide affiliated group, the remaining 33 percent of total Cd must be present in either the form of an unreduced compound, cations sorbed to the sediment, or a cation in lattice positions in a mineral. The presence of this 33 percent of total Cd as sorbed cations on the sediment is least likely.

Most of the Fe (about 75 percent of the total Fe) exists in the hydrous oxide form. The hydrous Fe oxide is a very important means of transportation of other metals (Appalachian Regional Commission, 1969). It is thus possible to infer that the elevated trace metal levels in the hydrous oxide affiliate category are all due to the reduction of hydrous Fe oxides.

A notable exception to the general trend of associations is Pb. It occurs below the limit of detection in the hydrous oxide fraction, and only a small amount is found in the adsorbed category. This knowledge, along with the fact that the Pb content in the sediment increases with decreasing grain size, points to the conclusion that the Pb present is in a strongly bonded state. It may exist as a distinct Pb compound or as substitutional cation in illite for K^+. Extremely elevated $SO_4^=$ contents (> 700 ppm) in Indian Fork waters were reported by Roger and Minear, Department of Environmental Engineering, University of Tennessee at Knoxville (1975, personal communication). X-ray diffraction data from Indian Fork sediments suggest that Pb may occur in these sediments as authigenic anglesite.

RESULTS AND DISCUSSION OF THE ANALYSES OF SIZE FRACTIONS OF SAMPLES

After separation of each sediment sample into the various size fractions, these fractions were weighed and stored. The weight percentages of all size fractions from each sampling site are presented in Table 3. Generally, the New River samples have the major portion of their sediment in the 5-53 μ size range, while most of Indian Fork sediment is in the 105-1000μ fraction. Also worthy of note is that a greater percentage of New River sediment rather than Indian Fork sediment falls into the 2-5μ and 0. 2-2μ size ranges. This increase in smaller sizes of sediment is a result of lower stream velocities in New River than in Indian Fork.

Indian Fork

The average metal concentrations of the several Indian Fork size fractions are given in Table 4. The outstanding relationship that these data suggest is that all nine metals are concentrated in the finer grain sizes. There is a very abrupt increase in metal concentrations of the 2-5μ size range over the metal levels in the coarser fractions. The 0. 2-2 μ size range has the same high level of concentrations as does the 2-5μ fraction. Also, the 105-1000 μ range has some higher metal concentrations than does the next finer size fractions. These

Table 3. Percentage of Sediment Sizes from Sampling Localities.

	Location	>1mm	105-1000μ	53-105μ	5-53μ	2-5μ	0.2-2μ	Totals*
Downstream	IFE	14	70	6.5	6.5	1.6	1.4	100
	IFD	19	69	2.3	5.8	3.1	1.1	100.3
	IFC	10	59	14	14	1.7	1.6	99.7
	IFB	13	65	6	12	2.4	1.2	99.6
	IFA	18	47	15	17	1.7	1.4	100.1

	NR1	8.1	21	14	46	6.6	5.3	101
	NR2	.2	6.4	5.7	51	28	9.4	100.7
	NR3	2.5	53	11	27	5.8	.6	99.6
	NR4	1.3	14	14	59	7.2	4.8	100.3

*The fact that the totals do not equal 100 percent is due to rounding off of numbers following scientific conventions.

elevated levels in the largest size fraction may be attributed to the encrustation of hydrous oxides on these larger particles.

A comparison of data from Table 5 with Table 4 illustrates the effects of the Indian Fork basin in concentrating metals in certain size fractions of sediment. Generally, the concentration of metals in the three coarsest size fractions correlate with the corresponding metals' average concentrations in shales. The two finer-grained fractions exhibit metal concentrations much higher than the average levels in shales. Some of the metals, Cd and Pb for example, occur well above their average in shales even in the coarsest size fraction. Again, it is possible that elevated metal values in the 105-1000 μ range of particles may be due to hydrous oxide encrustation.

Nickel is worthy of note because it occurs in concentrations lower than its shale abundance in the coarser sediment fractions, and about equal to shale values in the finer-grained sediment. It may be concluded that no matter how effective the enrichment of Ni by strip mining, the source strata are too poor in Ni initially to allow high levels of accumulations of this metal in the sediment; or, perhaps Ni is being preferentially removed from the system. In the aqueous environment, Cu maintains the same chemical relationships as does Ni (Massey and Barnhisel, 1972), thus, the same low initial (local) abundance is inferred. The remaining metals tend to occur in concentrations near their average shale abundances in the coarser size fractions. They become more concentrated in the 0.2-2 μ and 2-5 μ size ranges.

The calculated contribution of each fraction to the metal content of one gram of total sediment is proportional to the weight percent of that size fraction in the sediment. Table 6 presents the calculated

Table 4. Average Metal Concentrations of Indian Fork Sediment of Each Size Fraction (in μ g/g).

	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
IFA:									
105-1000μ	53	2.9	27	18	50	33	82	1148	37,825
53-105μ	68	1.8	20	16	37	35	60	561	39,234
5-53μ	46	3.9	31	13	41	33	92	464	37,072
2-5μ	106	5.2	73	38	104	60	198	1650	117,633
0.2-2μ	106	4.7	106	52	111	83	241	1467	82,534
IFB:									
105-1000μ	69	4.0	27	26	72	49	141	1397	82,526
53-105μ	59	2.0	25	21	49	37	70	750	38,351
5-53μ	53	3.2	39	14	52	33	82	713	40,448
2-5μ	106	5.8	85	42	109	61	203	2095	74,752
0.2-2μ	143	4.9	83	48	117	83	256	1687	90,097
IFC:									
105-1000μ	53	3.2	29	22	54	36	85	1170	47,128
53-105μ	42	1.8	22	22	42	37	67	549	39,312
5-53μ	57	2.7	36	14	49	33	119	949	48,208
2-5μ	123	6.4	97	51	109	63	218	2302	100,672
0.2-2μ	144	6.5	46	60	108	72	203	1600	104,519
IFD:									
105-1000μ	46	3.2	26	17	52	36	83	946	49,023
53-105μ	51	2.6	20	16	47	37	66	474	43,137
5-53μ	75	3.9	45	15	50	43	117	750	58,859
2-5μ	119	4.7	128	36	110	62	167	1836	71,167
0.2-2μ	119	4.6	70	46	99	87	204	1502	94,559
IFE:									
105-1000μ	63	3.5	26	22	50	43	95	974	40,359
53-105μ	36	2.4	22	13	39	37	66	515	35,468
5-53μ	57	2.7	34	16	58	35	110	703	42,117
2-5μ	88	6.2	103	39	109	49	173	2174	40,782
0.2-2μ	115	4.8	64	76	102	80	216	2269	64,851

Table 5. Average Elemental Abundance of Select Metals in μ g/g.

	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
Entire Crust	100	0.2	25	55	75	12.5	70	950	5.6×10^4
Shales	100	0.3	20	57	95	20	80	850	4.7×10^4

(After Krauskopf, 1967)

amounts of trace metals found in one gram of sediment (per size fraction) from each Indian Fork sampling site. These data represent the

Table 6. Calculated Metal Contribution from Each Size Fraction of Indian Fork Sediment (in μ g/g).

	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
IFA:									
105-1000μ	25	1.4	13	8.5	24	16	39	540	17,778
53-105μ	10	0.27	3	2.4	5.6	5.0	12	84	5885
5-53μ	7.8	0.66	5.3	2.2	7.0	5.6	16	79	6302
2-5μ	1.8	0.09	1.2	0.7	1.8	1.0	3.4	28	2000
0.2-2μ	1.5	0.07	1.5	0.73	1.6	1.2	3.4	21	1156
IFB:									
105-1000μ	45	2.6	18	17	47	32	92	908	53,642
53-105μ	3.5	0.12	1.5	1.3	2.9	2.2	4.2	45	2301
5-53μ	6.4	0.38	4.7	1.7	6.2	4.0	9.8	86	4854
2-5μ	2.5	0.14	2.0	1.0	2.6	1.5	4.9	50	1794
0.2-2μ	1.7	0.06	1.0	0.7	1.4	1.0	3.1	20	1081
IFC:									
105-1000μ	21	1.9	17	13	32	21	50	690	27,806
53-105μ	5.9	0.25	3.1	3.1	5.9	5.2	9.4	77	5504
5-53μ	8.9	0.41	5.4	2.1	7.4	5.0	18	142	7231
2-5μ	2.1	0.11	1.7	0.87	1.9	1.1	3.7	39	1711
0.2-2μ	0.9	0.10	0.74	0.96	0.70	0.20	3.3	26	1672
IFD:									
105-1000μ	32	2.2	18	12	36	25	57	653	33,826
53-105μ	1.2	0.06	0.46	0.37	1.1	0.85	1.5	10.9	992
5-53μ	4.4	0.23	2.6	0.87	2.9	2.5	6.8	44	3414
2-5μ	3.7	0.15	4.0	1.1	3.4	1.9	5.2	57	2206
0.2-2μ	23	0.05	0.77	0.51	1.1	0.96	2.2	17	1040
IFE:									
105-1000μ	44	2.5	18.2		35	30	67	682	28,251
53-105	2.3	0.16	1.4		2.5	2.4	4.3	34	2305
5-53μ	3.7	0.18	2.2		3.8	2.3	7.2	46	2738
2-5μ	1.4	0.1	1.7		1.7	0.78	2.8	35	653
0.2-2μ	2.1	0.07	0.9	1.06	1.43	1.12	3.02	32	908

contribution, of each size fraction analyzed, to the total trace metal content of the stream sediment.

New River

The tendency for the greatest concentration of metals to be in the finer-grained material is seen most explicitly in the New River sediments. As the data in Table 7 exhibit, the concentrations of all metals (except Mn) increase in the 2-5μ and 0.2-2μ ranges. Comparison of data between Table 7 and Table 4 points out that the sediment in New River generally contain about 10 percent more of any given metal in corresponding size ranges than does Indian Fork. The similarity of source rock does not permit either stream to become drastically

Table 7. Average Metal Concentrations of New River Sediment of Each Size Fraction (in μ g/g).

	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
NR1:									
105-1000μ	59	3.2	23	31	46	28	99	1393	41,721
53-105μ	65	2.5	29	29	47	27	93	391	30,435
5-53μ	67	2.6	49	23	48	27	101	510	30,409
2-5μ	108	4.2	79	41	98	48	204	794	53,042
0.2-2μ	112	6.2	98	53	133	51	271	1191	102,670
NR2:									
105-1000μ	47	3.3	27	29	48	27	86	1356	38,467
53-105μ	49	3.3	28	30	48	28	102	364	32,789
5-53μ	80	4.2	48	26	64	28	124	453	41,508
2-5μ	110	4.3	79	30	91	45	180	812	69,548
0 2-2μ	114	7.1	104	54	117	51	226	1813	102,661
NR3:									
105-1000μ	46	2.8	20	34	41	27	80	1568	38,068
53-105μ	61	4.7	32	32	66	27	123	547	29,591
5-53μ	65	3.6	52	23	65	27	133	787	38,088
2-5μ	106	5.8	90	55	127	51	294	1962	94,588
0.2-2μ	126	6.5	99	71	156	50	319	1819	104,787
NR4:									
105-1000μ	46	3.5	25	36	53	27	87	1655	33,499
53-105μ	68	3.8	35	30	52	28	119	615	29,876
5-53μ	68	3.4	53	23	57	27	104	640	30,295
2-5μ	108	6.0	80	41	114	44	228	1585	51,012
0.2-2μ	123	5.4	104	56	123	50	228	1820	95,168

enriched in a particular metal. It is logical to assume that the strip mining around the New River basin would liberate trace metals in the same magnitude of concentration as would the strip mining around Indian Fork.

In Table 8 the actual contribution from each size fraction (per gram) of New River sediment is presented. Comparing Table 8 with Table 6, it can be seen that the actual metal contribution from the 0.2-2 μ and 2-5 μ fractions generally vary from 50 percent to 400 percent higher in New River sediments than in Indian Fork sediments. The extreme difference between the two stream systems can be seen by examining the Zn contributions. Zinc contributions from the 0.2-2μ fractions in New River average 10 μ g/g of sediment, while the Zn concentrations from the 0.2-2μ fractions of Indian Fork average 2.5μ g/g of sediment. A similar ratio (of about 4 : 1) of New River's higher contribution of Zn can be seen in the averages of the 5-53μ fractions. In fact, the only fraction of Indian Fork sediment which is higher in Zn contribution (than is New River) is the 105-1000μ size range.

Table 8. Calculated Metal Contribution from Each Size Fraction of New River Sediment (in μ g/g).

	Cr	Cd	Co	Cu	Ni	Pb	Zn	Mn	Fe
NR1:									
105-1000μ	12	0.67	4.8	6.5	9.7	5.9	21	293	8761
53-105μ	9.1	0.35	4.1	4.1	6.6	3.8	13	55	4261
5-53μ	31	1.2	23	11	22	12	47	235	13,988
2-5μ	7.1	0.28	5.2	2.7	6.5	3.2	14	52	3501
0.2-2μ	5.9	0.33	5.2	2.8	7.1	2.7	14	63	5442
NR2:									
105-1000μ	3.0	0.21	1.7	1.9	3.1	1.7	5.5	87	2462
53-105μ	2.8	0.19	1.6	1.7	2.7	1.6	5.8	21	1869
5-53μ	41	2.1	25	13	33	14	63	231	21,169
2-5μ	31	1.2	22	0.84	26	13	50	227	19,473
0.2-2μ	11	0.67	9.8	5.1	11	4.8	21	170	9650
NR3:									
105-1000μ	24	1.5	11	18	22	14	42	831	20,176
53-105μ	6.7	0.52	3.5	3.5	7.3	3.0	14	60	3255
5-53μ	18	0.97	14	6.2	18	7.3	36	213	10,283
2-5μ	6.2	0.34	5.2	3.2	7.4	3.0	17	114	5486
0.2-2μ	0.8	0.04	0.59	0.43	0.94	0.3	1.9	11	629
NR4:									
105-1000μ	6.4	0.49	3.5	5.0	7.4	3.8	12	232	4690
53-105μ	9.5	0.53	4.9	4.2	7.3	3.9	17	86	4183
5-53μ	39	2.0	31	14	34	16	61	378	17,874
2-5μ	7.8	0.43	5.8	3.0	8.2	3.2	16	114	3673
0.2-2μ	6.1	0.26	5.0	2.7	5.9	2.4	11	87	4568

The cause of the above described difference in metal contributions is that the majority of New River sediments are a finer grain size than are the Indian Fork sediments, Table 3. The 0.2-2μ and 2-5 μ fractions of sediment are over twice as abundant in New River sediment as their counterparts in Indian Fork. An increased quantity of these finer grain sizes increases the overall metal content of New River sediment (due to higher metal concentrations in these finer-grained fractions).

RESULTS AND DISCUSSION OF THE X-RAY DIFFRACTION ANALYSES

The mineralogy of the sediments in the region of sampling is consistent within each size fraction. Regardless of locality, there is no appreciable mineralogic difference between samples in any given

Table 9. Results of X-ray Analyses of Sediments.

Sediment Fraction	Minerals Identified
New River, Indian Fork: All Sites	
105-1000μ	Quartz: Dominant Illite Kaolinite Goethite
53-105μ	Quartz: Dominant Illite Kaolinite Goethite (Very Minor Anglesite Possible in New River Samples)
5-53μ	Quartz: Dominant Illite Kaolinite (Very Minor Anglesite and Goethite) Chlorite: Minor
2-5μ	Illite: Dominant Kaolinite: Dominant Quartz Anglesite Montmorillonite Chlorite
0.2-2μ	Illite Kaolinite Montmorillonite Chlorite

size range. There is a transition in mineralogy between the various size fractions. Quartz dominates the coarser material whereas clay minerals are the major components of the finer-grained sediments. Quartz is not present in detectable amounts in the 0.2-2μ size fraction. The results of all x-ray analyses are presented in Table 9.

Anglesite has been tentatively identified by the presence of the 100 relative intensity peak and several subsidiary peaks. As previously stated, elevated Pb values in the finer-grained sediment does not correlate with Pb adsorption onto clay surfaces. This strongly suggests the presence of Pb in some discrete chemical form. Elevated $SO_4^=$ values in the Indian Fork waters indicate that the fluvial environment may be favorable for the stability of sulfate compounds. Since Pb is not adsorbed to the clays, it probably exists in the form of $PbSO_4$ or some other species not associated with layered silicates.

SUMMARY AND CONCLUSIONS

The influx of tributaries into major streams was shown to markedly affect metal content of the entire < 1 mm sediment. In the cases of samples IFB, IFC, and IFD the increase in metal content was due to higher concentrations of metals in most of the size fractions of the sediment. In the case of sample NR2 the major reason for the elevated metal content was an increase in the amount of the 0.2-2 μ and 2-5 μ size ranges. These two fractions were enriched over the coarser sediment in the concentrations of all metals.

Data from chemical extractions suggested that a large quantity of the metals associated with particulate material was also associated with hydrated iron oxides. On an average, about 40 percent of each metal was associated with hydrous oxides. Both Mn and Fe were seen to comprise the major percentage of cations in the category of hydrous oxides. It is, therefore, suggested that these two cations may be the principal metallic ions found in colloidal material in the streams under study. These Fe-Mn colloids were shown to be a significant transporting agent for other trace metals. Copper Pb and Cr are the only metals which do not appear to closely associated with hydrous oxides.

It was found that the 0.2-2μ and 2-5μ size fractions contained the highest concentrations of most metals studied. Generally, the coarser fractions had concentrations of metals near their respective abundances in shales. The two finer-grained fractions showed enrichment over the average abundance in shales. Since Cu and Ni were found in levels which only approximated their average sedimentary abundance in the finer-grained material, it is suggested that Ni and Cu are either scarce in the local strata or are preferentially removed from the system.

Data from x-ray diffraction analyses have shown quartz to be dominant in the coarser-grained sediments. The 0.2-2μ and 2-5μ fractions consisted mainly of the clay minerals, kaolinite, illite, montmorillonite, and chlorite. Goethite and anglesite were also identified by x-ray diffraction.

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NEOGENE MOLLUSCAN ASSEMBLAGES ALONG THE CHOWAN RIVER, NORTH CAROLINA

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ABSTRACT

Nine fossil assemblages (paleocommunities) are recognized in the Pliocene Yorktown Formation exposed along the Chowan River, North Carolina. Molluscan species dominate in eight communities. A coral Septastrea and an echinoid Mellita are very abundant in two communities. One community is recognized on the basis of abundant polychaete(?) worm burrows.

Molluscan paleocommunities are dominated by shallow infaunal, suspension feeding bivalves. Deposit feeding bivalves occurring in eight communities may represent temporally stable populations utilizing a constant deposit food resource. The polychaete(?) community contained only infaunal deposit feeding organisms.

Discontinuous community transition, revealed by a study of vertical sequences, seems to be related to faunal migration in response to changing environmental conditions. One vertical sequence records four molluscan communities in transition from a shallow shelf community to a brackish water lagoonal or estuarine community. The vertical sequence of fossil communities and sediments indicates a regression of the late Yorktown sea.

Sediment texture, sedimentary structures, and molluscan species indicate that five of the assemblages lived in shallow shelf environments, three lived in lagoonal or open bay environments, and one lived in a brackish estuarine environment.

INTRODUCTION

The very fossiliferous, Pliocene Yorktown Formation is well exposed along the west bank of the Chowan River in northeastern North Carolina. The molluscan species of this part of the Yorktown have been the subject of detailed taxonomic analysis (Gardner, 1943; 1948), but no thorough paleoecologic synthesis has been attempted. This paper discusses nine fossil assemblages (paleocommunities) that are found in the

Pliocene deposits along the Chowan River. Important goals were the analysis of community trophic structure and the demonstration of community succession.

Yorktown outcrops on the west bank of the Chowan River lie along a north-south line that is nearly parallel to regional depositional strike of about N15°E (Figure 1). The occurrence of a series of faunally similar fossil assemblages nearly parallel to depositional strike suggests that temporal differences among the assemblages are slight. Within the relatively short time interval necessary for the deposition of Yorktown sediments along the Chowan River, no evolutionary changes of molluscan species were discerned.

Acknowledgments

This study is a modified portion of a Ph. D. dissertation done at the University of North Carolina, Chapel Hill. Walter H. Wheeler served as dissertation advisor, and provided invaluable assistance and encouragement. Druid Wilson, U. S. Geological Survey, assisted with taxonomic problems. The field work for the project was supported by a grant from the Division of Mineral Resources of the N. C. Department of Conservation and Development.

STRATIGRAPHY

The Yorktown Formation, composed of silty and clayey, very fine sands, crops out from the Rappahanock River in Virginia to the Neuse River in North Carolina (Figure 1). Hazel (1971b) proposed an ostracode assemblage zonation for the Yorktown Formation in North Carolina and Virginia. According to this zonation the beds along the Chowan River are placed in the upper most Puriana mesacostalis (Edwards) assemblage zone and are among the youngest Yorktown exposures. On the basis of planktic foraminifers, Hazel (1971b) suggested that the Chowan River beds should be assigned to the lower Pliocene however, his more recent studies indicate an upper Pliocene or possibly an early Pleistocene age (Hazel, 1975, personal commun.). Akers (1972) determined a lower to middle Pliocene age for planktic foraminifers collected from outcrops in Virginia that are stratigraphically lower than the Chowan River Yorktown. The molluscan assemblage and the lithologic sequence of the Chowan River Pliocene are distinctively different from those of the older Yorktown. These differences indicate the need to re-evaluate the placement of the Chowan River deposits in the Yorktown Formation. Although this is a significant problem, it does not alter the paleoecological conclusion of this study.

Along the Chowan River, 0. 3 to 6. 0 m of fossiliferous strata are exposed in a series of bluffs separated by broad post-Pliocene stream valleys. Fossiliferous marine strata are usually overlain by

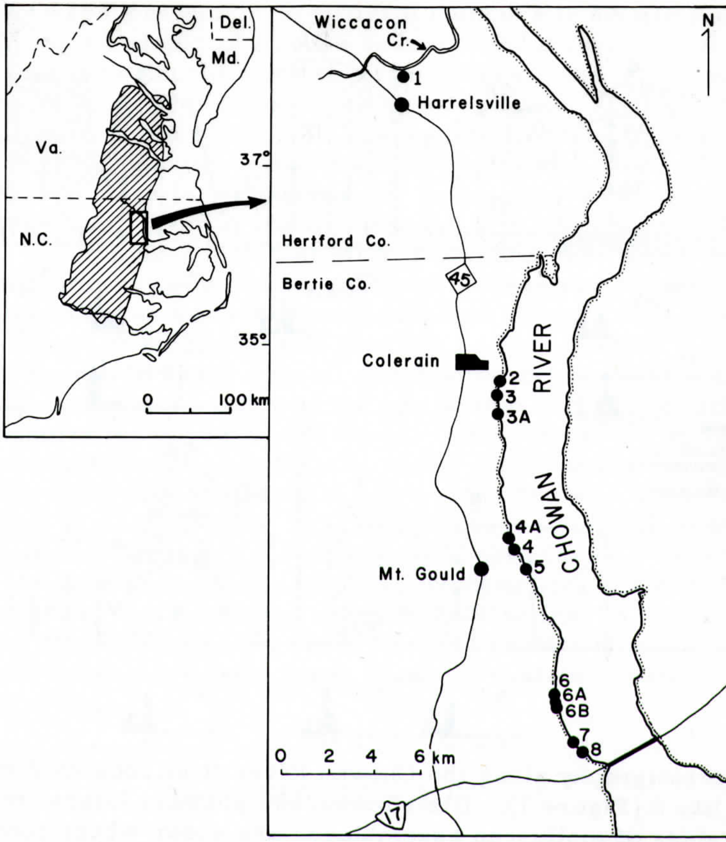

Figure 1. Location map showing outcrop area of Yorktown Formation (cross-hatched) and Yorktown localities along Chowan River.

coarse, cross-bedded fluvial sands and clays of Pleistocene age. Possible correlations and facies relationships along the Chowan River are shown in Figure 2.

METHODS

Thirty-eight bulk samples were collected from nine localities. At each locality a detailed stratigraphic section was measured and field observations on the orientation of fossils, presence or absence of sedimentary structures, and other physical characteristics of the fauna and sediment were made. Sample volumes (matrix and fossils) were estimated by placing each sample in a graduated plastic container of known volume. Fossils were separated by washing samples on sieves. The

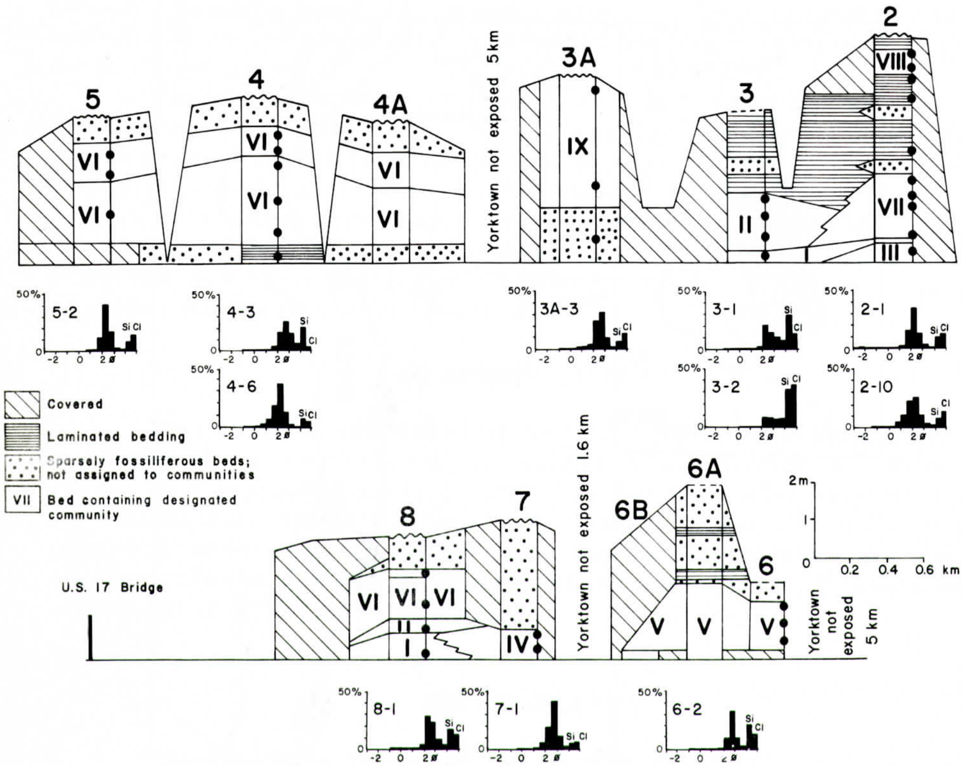

Figure 2. Stratigraphy along the Chowan River from locality 2 to locality 8 (Figure 1). Distribution and possible lateral relationships of molluscan assemblages are shown where control is adequate. Samples indicated by large dots. Results of selected sediment analyses are shown as histograms. Number next to histogram refers to locality and to stratigraphic position of sample. Sample 1 collected nearest base of outcrop. Datum is river level. Surficial sediments overlying Yorktown not shown.

sieve with the finest mesh retained all material coarser than 0.8 mm. All identifiable molluscs were picked from the washed sample, identified to species and counted. Abundance data and species found are presented in Table 1.

FAUNAL ANALYSIS

Samples exhibiting faunal homogeneity and similar dominant species were grouped to form a total of nine fossil assemblages. The two distinctive species chosen to designate each assemblage were picked because they were present in significant numbers in all samples of the community, were conspicuous at the outcrop, and did not occur or were somewhat less conspicuous in other assemblages. One group is characterized in part by a coral and another by an echinoid. These organisms are used because of their unusual abundance and conspicuousness.

Ager (1963) equates a fossil assemblage with a fossil community, where the assemblage is defined as all organisms found together in a particular stratum. This is the definition of a paleocommunity used in this study, with the exception that microfossil and rare megafossil taxa are excluded from the community analysis. These partial communities or fossil assemblages are recurrent and occur in more than one stratigraphic units and at more than one locality.

The degree to which a fossil community represents the fauna that actually lived on a portion of the sea bottom will depend primarily on the transportation of dead individuals from their living habitats. Fossil communities that accumulated under conditions of low environmental energy will probably contain more autochthonous individuals and will thus have a much greater resemblance to the original living community. Applying Johnson's (1960) physical criteria for determining the extent to which an assemblage of fossil organisms has been affected by transportation, the molluscan communities defined in this study are ranked from (1) the community least likely to contain allochthonous individuals to (9) the community most likely to contain allochthonous individuals (Table 2).

COMMUNITY DESCRIPTIONS

Community I Mercenaria - Septastrea. The ahermatypic coral Septastrea cf. S. marylandica (Conrad) occurs in all communities, but it is rare in most and is usually found as widely scattered small colonies. In community I, Septastrea forms ramose coralla that are 0.1 to 0.6 m high with numerous frequently anastomosing branches. The coral heads have grown upward from initial attachments on large bivalves, especially Argopecten and Mercenaria. Most of the colonies seem to have started growth at about the same time on a hard bottom covered with bivalve shells and eventually reached roughly the same maximum heights. The coral heads, in their approximate upright growth positions, form a loose thicket-like framework within which are situated abundant articulated bivalves. Four common bivalves of this assemblage Mercenaria campechiensis, Eontia carolinensis, Cumingia medialis, and Modiolus ducatellii are usually found articulated. The coral thicket may have altered the microhabitats within its boundaries by acting as a current baffle that allowed accumulation of fine sediments and by providing hard substratum for attachment of epifaunal organisms. Certain species unique to coral substratum such as the boring clam Lithophaga were present, but other epifaunal species were no more abundant than in other communities. As most of the molluscan species considered in this study are infaunal, they would not have been able to take maximum advantage of the coral substratum. Because of the very small and unstable initial attachment, it seems likely that sediment accumulated slowly around the coral colonies, helping to anchor them by burying their bases and low branches. If this assumption is correct, then the molluscan fauna presently associated with the coral would have existed during the growth and development of the coral thicket.

Community II Modiolus - Cumingia. This low diversity community is found in very clayey and silty, very fine sands. The large mussel Modiolus ducatellii, the species most characteristic of this community, is often found articulated and in its near vertical living position. Cumingia medialis, an infaunal deposit feeder, was very common in clayey sands at locality 3. Burrows, 0. 5 to 2. 0 cm in diameter, filled with fine sand and shell fragments reveal the presence of an infaunal, possibly deposit feeding invertebrate, whose body was not preserved. The low diversity of this community is probably related to the muddy unstable bottom that would be difficult for most infaunal bivalves to inhabit.

Community III Argopecten - Glycymeris. The only species of pectinid found, Argopecten eboreus, is present in all molluscan communities, but it is most abundant at locality 2 where it occurs in great numbers in the lower 0. 6 m of the outcrop. At this locality specimens of A. eboreus are usually preserved as imbricate, convex-up, single valves and as articulated valves with the plane of the commissure parallel to bedding. Argopecten was probably an active epifaunal bivalve, as are most extant pectinid species (Waller, 1969).

Two species of Glycymeris, G. americana and G. subovata are present, with the latter being the most abundant. Most extant glycymerids are very shallow burrowers that live with the plane of the commissure from 60 to 70^{o} from the vertical (Stanley, 1970). The two Pliocene species seem to have had similar modes of life because they are often found articulated with their commissural planes nearly parallel to bedding surfaces.

Community IV Turritella - Panopea. Most communities defined in this study are dominated by bivalves. The group of samples included in community IV is unique because of the unusual abundance of the shallow infaunal, ciliary suspension feeding gastropod, Turritella cf. T. variablis. Turritella communis Risso is an extent species that lives just below the bottom in muddy sediments, but maintains connection with the overlying water mass by means of a large inhalant siphon formed by the foot and a smaller exhalant siphon formed by the mantle edge (Fretter and Graham, 1962). This mode of life, somewhat unusual among the gastropods, is inferred to be the type used by T. cf. T. variablis.

Two deep infaunal bivalves, Panopea goldfusii and Ensis directus, are also common in this community. The former species was found in living position in shell and sand filled burrows 3 to 4 cm in diameter.

Community V Nassarius - Mulinia. Nassarius chowanensis was a scavenger that presumably fed on organic detritus and small bits of carrion in the uppermost layers of muddy sands. Mulinia lateralis is abundant only at locality 6. Living individuals of M. lateralis are often found in lagoons, sounds, and bays and especially in clayey substrata (Parker, 1956; Sanders, 1956).

Community VI Crassatella - Macrocallista. The large, shallow infaunal, suspension feeding bivalves Crassatella undulata and Macrocallista reposta are often found articulated, with their commissures parallel to bedding. Epifaunal sessile bivalves Plicatula marginata and Ostrea sculpturata are very abundant in this community. Plicatula occurs in groups of 2 to 8 individuals attached to small shells. Ostrea is usually found as solitary individuals cemented to either large bivalves or coral.

Community VII Argopecten - Mellita. Numerous specimens of the irregular echinoid, Mellita aclinensis Kier were found in a 10 cm interval at locality 2 (Figure 2). Within this interval M. aclinensis is in its horizontal living position. Kier (1972) suggests that this echinoid probably lived 20 to 30 mm below the sediment surface in about 3 to 15 m of water on a firm sand bottom. Argopecten eboreus is usually disarticulated with valves in a convex-up orientation.

Community VIII Corbicula - Rangia. Corbicula densata and Rangia clathrodonta are shallow infaunal, suspension feeders. Recent species of Rangia commonly inhabit brackish environments such as estuaries, lagoons, or bays (Parker, 1960). In the Potomac River Rangia cuneata Gray is abundant where salinities are seldom greater than 15 $^{o}/oo$ (Pfitzenmeyer and Drobeck, 1964). Corbicula manilensis (Philippi) is found in slightly brackish to fresh water in many estuaries and rivers of the United States (Diaz, 1974). The fossil specimens of Corbicula often have the corroded umbo typical of calcium carbonate valves that have been exposed to fresh or nearly fresh water. In the bed containing this community (Figure 2, locality 2), Corbicula is more abundant near the top of the unit and Rangia is more abundant near the base. This vertical sequence suggests a decrease in salinity during deposition. Because coral and many other species of bivalves are found with articulated specimens of C. densata and R. clathrodonta in a medium sand matrix, it seems probable that the community may have lived in an environment (bay mouth, inlet, lagoon) where faunal mixing occurred. I have observed R. cuneata Gray in Albemarle Sound, living in great abundance immediately behind the barrier bar that forms the northern portion of the outer bands of North Carolina. The substratum is often the medium sand of a washover fan, that contains transported bivalves, gastropods, and occasionally coral fragments typical of the marine shelf. This area seems to be a possible modern analog for the Pliocene Rangia - Corbicula community.

Community IX Polychaete (?) Community. Community IX has

Table 1. Modes of Life, Feeding Types and Abundances of Chowan River Yorktown Mollusks.

	Mode of life/ Feeding type[1]	Abundances of species in communities[2]							
		I	II	III	IV	V	VI	VII	VIII
Bivalvia									
*1. *Abra subreflexa* (Conrad)	SI/D?	0	0	17.9	2.6	2.8	1.9	1.1	0.7
2. *Aligena aequata* (Conrad)	SI?/S	1.3	0	5.1	4.2	2.0	1.8	0.6	0.3
3. *A. chowanensis* Gardner	SI?/S	0	0	0	0.5	0.5	1.0	0	0
4. *Anomia aculecta* Gmelin	E/S	0.5	0	0.1	0	0	0.1	0	0
*5. *Argopecten eboreus* (Conrad)	E/S	3.3	0.8	12.9	8.3	3.2	4.2	7.6	5.7
*6. *Astarte berryi* Gardner	SI/S	0	0	14.6	0	0	0.5	2.8	0
*7. *A. concentrica* Conrad	SI/S	0.9	11.0	11.6	7.4	2.5	3.2	3.3	16.3
8. *Bornia triangula* Dall	E?/S	0	0	0	0.6	0	0.8	0	0
9. *Carditamera arata* (Conrad)	SI/S	0	0	0.1	0	0	1.0	0	0
*10. *Cavilinga trisulcata* (Conrad)	DI/S	0	0	0	0	0	6.3	0	8.7
11. *Chione grus* (Holmes)	SI/S	0	0	0.1	0.7	0	0	0	0
*12. *Corbicula densata* (Conrad)	SI/S	0	0	0	0	0	0	0	21.0
*13. *Corbula cf. C. conradi* Gardner	SI/S	0	0	0	20.6	2.0	0	0	0
*14. *C. inequalis* Say	SI/S	9.0	7.0	29.2	23.2	18.0	28.2	9.2	123.7
*15. *Crassatella undulata* (Say)	SI/S	0.2	0	0.8	1.8	1.5	4.1	0	1.0
*16. *Crassinella lunulata* (Conrad)	SI/S	0.5	0	17.0	1.6	1.0	5.0	0	6.0
17. *Crenella precursor* Gardner	E/S	0	0	0	0	0.5	0	0	0
*18. *Cumingia medialis* (Conrad)	DI/D	7.4	1.7	0.4	3.4	3.0	1.1	0	2.3
*19. *Cyclocardia granulata* (Say)	SI/S	0.9	0	42.0	13.1	9.0	18.7	7.1	11.0
20. *Cyrtopleura arcuata* (Conrad)	DI/S	0	0	0	0	0.7	1.0	0	0
*21. *Diplodonta acclina* (Conrad)	DI/S	0.5	0	1.7	0.2	0.9	8.1	0	0.7
22. *D. subrexa* (Conrad)	DI/S	0	0	0	0.3	0	0	0	0
23. *Divaricella quadrisulcata* (d'Orbigny)	DI/S	0	0	0	0.7	0	0.7	0	0
24. *Donax fossor* Say	SI/S	0	0	0	0	0	0.9	0	1.7
*25. *Ensis directus* (Conrad)	DI/S	1.2	4.0	2.9	13.9	6.3	5.3	1.1	3.0
26. *Ensitellops protexta* (Conrad)	SI?/S	0.2	0	0.8	0	0	0.7	0	0
*27. *Eontia carolinensis* (Conrad)	SI/S	4.7	0.5	1.4	1.4	2.5	5.8	0	4.0
28. *Erycina carolinensis* Dall	SI/S	0	0	0.1	0	0	0	0	0
29. *Fabella calpix* (Gardner)	SI?/S	1.2	2.0	0	1.2	1.0	1.7	0	0.3
*30. *Gemma magna* Dall	SI/S	0.3	0	1.3	1.8	25.0	3.3	0	6.3
*31. *Glycymeris americana* (DeFrance)	SI,E/S	0.8	0	2.5	1.7	2.4	3.4	0	0
*32. *G. subovata* (Say)	SI,E/S	0	0	26.2	0.3	0	0	2.2	8.0
*33. *Gouldia metastriata* (Conrad)	SI/S	0	0	3.6	10.7	0	5.2	0.5	1.3
34. *Lirophora latilirata* (Conrad)	SI/S	0	0	0	0.5	0	0	0	0
35. *Lithophaga sp.*	Ib/S	0.2	0	0	0	0	0.9	0	0
36. *Lucinoma contracta* (Say)	DI/S	0	0	0	0.7	0	1.4	0	5.3
*37. *Macrocallista reposta* (Conrad)	SI/S	0	0	0	0	0	10.5	0	14.7
*38. *Mercenaria campechensis* (Gmelin)	SI/S	3.7	1.3	4.6	5.7	6.9	6.3	1.2	20.0
*39. *Modiolus ducatellii* (Conrad)	SI,E/S	1.5	3.6	0	1.1	0.5	1.1	0	0.3
*40. *Mulinia lateralis* (Say)	SI/S	0	0	0.9	2.2	56.5	2.0	0	0
41. *Mysella cf. M. bladensis* Gardner	Co/S	0.3	0	0.5	0	0	3.0	0	0
*42. *Nucula proxima* Say	SI/D	3.0	3.0	25.3	13.4	9.7	11.7	7.0	P
43. *N. taphria* Dall	SI/D	0	0	0	7.0	0	0	0	0
*44. *Nuculana acuta* (Conrad)	SI/D	3.7	1.0	8.6	10.1	14.8	39.8	3.0	11.0
45. *Ostrea compressirostra* Say	Ec/S	0	0	0.1	0	0	0	0	0
*46. *O. sculpturata* Conrad	Ec/S	0.4	0	1.8	1.9	0.7	15.2	1.0	18.7
47. *Pandora tuomeyi* Gardner and Aldrich	SI/S	0	0	1.2	2.1	2.0	3.4	0	4.0
48. *Panopea goldfussii* Wagner	DI/S	0	0	0	0.8	0	0	0	0
*49. *Parvilucina crenulata* (Conrad)	DI/S	55.2	32.0	35.8	64.7	58.0	20.3	12.0	16.0
50. *P. multilineata* (Tuomey and Holmes)	DI/S	0	0	0	0	0	3.2	0	0.7
*51. *Pitar sayana* (Conrad)	SI/S	0.5	0	3.2	7.6	6.5	5.9	0	0
52. *Pleuromeris tridentatus* (Say)	SI/S	0	0	3.3	0.4	0	5.1	0	P
*53. *Plicatula marginata* Say	Ec/S	0	0	2.1	0	0.5	27.0	0	13.0
54. *Pteromeris perplana* (Conrad)	SI/S	0.3	0	0	0	0	3.4	0	1.0
55. *Rangia clathrodonta* (Conrad)	SI/S	0	0	0	0	0	0	0	P
*56. *Spisula delumbis* (Conrad)	SI/S	0.2	2.0	13.7	2.5	1.0	24.0	4.3	28.7
57. *Stewartia anodonta* (Say)	DI/S	0	0	0	0.7	0	0	0	0
*58. *Syndosmya aequalis* (Say)	SI/D	10.1	2.5	13.0	0.9	5.0	4.0	1.7	2.7
*59. *Tellina declivis* Conrad	SI/D	1.0	0	8.0	6.1	2.8	17.6	0.7	10.7

very sparse molluscan fossil molds in an intensively bioturbated silty, fine sand. The burrows consist of roughly circular, elongated, curved tubes, 1 to 2 cm in diameter, filled with fine to medium sand. The burrows are irregular, but are often parallel to bedding indicating that the organism responsible for burrowing may have been a shallow infaunal deposit feeder in a level-bottom subtidal environment (Rhoads, 1967). The nature of the burrows suggests that a polychaete worm may have been the soft-bodied burrower.

Table 1. Continued.

	Mode of life/ Feeding type[1]	Abundances of species in communities[2] I	II	III	IV	V	VI	VII	VIII
60. *Thracia transversa* H.C. Lea	SI/S	0	0	0	0	0	0.7	0	0
61. *Varicorbula cf. V. caloosae* (Dall)	SI/S	0	0	0	P	P	0	0	0
62. *Verticordia emmonsii* Conrad	SI?/S?	0	0	1.0	0	0	0	0	0
63. *Yoldia laevis* (Say)	SI/D	0.6	2.0	0	0.4	2.0	3.4	0	0.7
Gastropoda									
64. *Acteocina canaliculata* (Say)	SI/C	0	0	0.3	0.7	0	1.2	0	0
65. *Acteon novellus* Conrad	SI?/C?	0	0	0	0.5	0	0	0	0
66. *Aesopus cf. A. smithfieldensis* (Mansfield)	E?/Co?	0	0	0	0.9	0	0	0	0
67. *Anachis cf. A. avara* (Say)	E/C	2.5	0	4.2	2.4	3.0	1.8	0	0
68. *Aurinia obtusa* (Emmons)	SI,E/C	0	0	0	0.5	0	0	0	0
69. *Busycon maximum* (Conrad)	SI,E/C,Sc	0.3	0	0.2	0.3	0	0.7	0	0
70. *Busycotypus canaliculatus* (Linné)	SI,E/C,Sc	0.3	0	0	0.3	1.0	0.4	0	0
71. *Calyptraea centralis* (Conrad)	E/S	0	0	0.2	0	0	0	0	0
72. *Clathrus antillarum* (DeBoury)	E/C	0.2	0	0	1.3	2.1	0.6	0	0
73. *Cochliolepis concava* (H.C. Lea)	E/P	0	0	0	0	0	0.5	0	0
74. *Cochliolepis sp.*	E/P	0.2	0	0	0	0	0	0	0
75. *Crepidula aculeata* (Gmelin)	E/S	0	0	1.3	0.3	0	0	0	0
*76. *C. fornicata* (Linné)	E/S	0.8	5.0	0.9	3.4	1.0	2.6	0	0
77. *C. plana* Say	E/S	0.7	0	0.3	0	0	0.8	0	0
78. *Crucibulum multilineatum* (Conrad)	E/S	P	0	0	2.0	0	0.7	0	0
79. *Cryoturris cf. C. magnoliana* Olsson	E?/C?	0	0	0.1	0.5	0.5	1.3	0	0
80. *Cyclostremiscus sp.*	E?/P?	0	0	0.4	0.4	0	0	0	0
81. *Cymatosyrinx cf. C. eburnea* (Conrad)	E?/C	0	0	0	0.5	0	0	0	0
82. *C. lunata* (H.C. Lea)	E?/C	0	0	0.1	0	0	0.5	0	0.7
83. *C. cf. C. zizac* Gardner	E?/C	0	0	0	0.5	0	0	0	0
84. *Cypraeolina lachrimula* (Gould)	E/?	0.2	0	0.7	0.4	0	0.3	0	0
85. *Diodora redimicula* (Say)	E/H	0	0	0	0	0	P	0	0
*86. *Epitonium cf. E. pratti* Gardner	E/C	0	0	0	0	10.0	0.3	0	0
87. *Eupleura cf. E. caudata* (Say)	E/C	0.5	0	0	0	0	0	0	0
88. *Ilyanassa granifera* (Conrad)	E/Sc	0.3	0	0	0	0.5	0.8	0	0
89. *I. cf. I. porcina* (Say)	E/Sc	0.2	0	0	0.4	0	0.3	0	0
90. *Lemintina granifera* (Say)	E/S	0	0	0.2	0.1	0	0.8	0	0
91. *Liotia cf. L. pergemma* Gardner	E?/H?	0	0	0.2	0	0	2.9	0	0
92. *Lunatia heros* (Say)	SI/C	0.2	0	0	0	0	1.3	0	0
93. *Marginella bella* (Conrad)	E/C	0.4	0	0.3	1.5	0	2.0	0	0
94. *M. denticulata* Conrad	E/C	0.5	0	0	0.4	0	0	0	0
95. *M. limatula* Conrad	E/C	0	0	0.3	0.5	1.5	2.0	0	0
96. *Mitrella communis* (Conrad)	E/C	0	0	0	0	0	P	0	0
97. *Mitrella sp.*	E/C	0	0	0.1	0	0	0	0	0
*98. *Nassarius chowanensis* Gardner	E/Sc	7.3	0	1.8	15.9	65.5	8.0	0	0
99. *Odostomia aff. O. conoidea* (Brocchi)	E/P	0	0	0.2	0	0	0	0	0
100. *O. seminuda* (Adams)	E/P	0	0	0	0.9	0	0	0	0
*101. *Olivella mutica* (Say)	SI/C	0.2	0	2.0	6.0	7.5	10.5	1.7	0
102. *Polinices duplicatus* (Say)	SI/C	1.2	0	1.3	2.1	2.5	3.1	0	0
103. *Seila cf. S. adamsii* (H.C. Lea)	SI/H	0.5	0	0.3	0.6	0.5	1.0	0	0
104. *Strombiformis eborea* (Conrad)	E/P	0.5	0	0.3	0.4	0.5	0	0	0
105. *Teinostoma goniogyrus* Pilsbry and McGinty	?/?	0	0	0.1	0	0	0	0	0
106. *T. nanum* (Issac Lea)	?/?	0.2	0	0	0	0	0	0	0
107. *Terebra cf. T. neglecta* Emmons	E?/C	0	0	0	0.7	0	1.0	0	0
108. *Tortifusus curvirostris* Conrad	E/C?	0	0	0	0	0	P	0	0
109. *Triphora bartschi* (Olsson)	E?/C?	0	0	0.1	0	0	0	0	0
110. *Turbonilla nivea* (Stimpson)	E/P	0.3	0	0.1	0.3	0	0.5	0	0
111. *T. interrupta* (Totten)	E/P	2.3	0	1.0	1.0	0.5	1.0	0	0
*112. *Turritella cf. T. variablis* Conrad	SI/S	3.0	0	7.5	200.7	24.6	17.4	9.4	0
113. *Urosalpinx cf. U. rusticus* (Conrad)	E/C	0.7	0	0	1.7	0.5	1.0	0	0
114. *U. trossula* (Conrad)	E/C	0.2	0	0.1	0	0	1.0	0	0
115. *Vexillum cf. V. holmesii* (Dall)	E/C	0	0	0	0	0	0.5	0	0
Scaphopoda									
116. *Dentalium attenuatum* Say	E/D,C	0.2	0	1.2	1.3	0	0	1.2	0

[1] Feeding type

Suspension = S
Deposit = D
Herbivore = H
Carnivore = C
Scavenger = Sc
Parasite = P
Commensal = Co

Mode of life

Deep Infaunal = DI
Shallow Infaunal = SI
Epifaunal = E
Epifaunal (cemented) = Ec
Borer = Ib

[2] Abundance is given as the mean of the densities (number of individuals/liter of sample) for all samples in a community containing the species. Specimens obtained from spoil or selectively picked from the outcrop are indicated with a P.

* Species which occur in trophic nuclei.

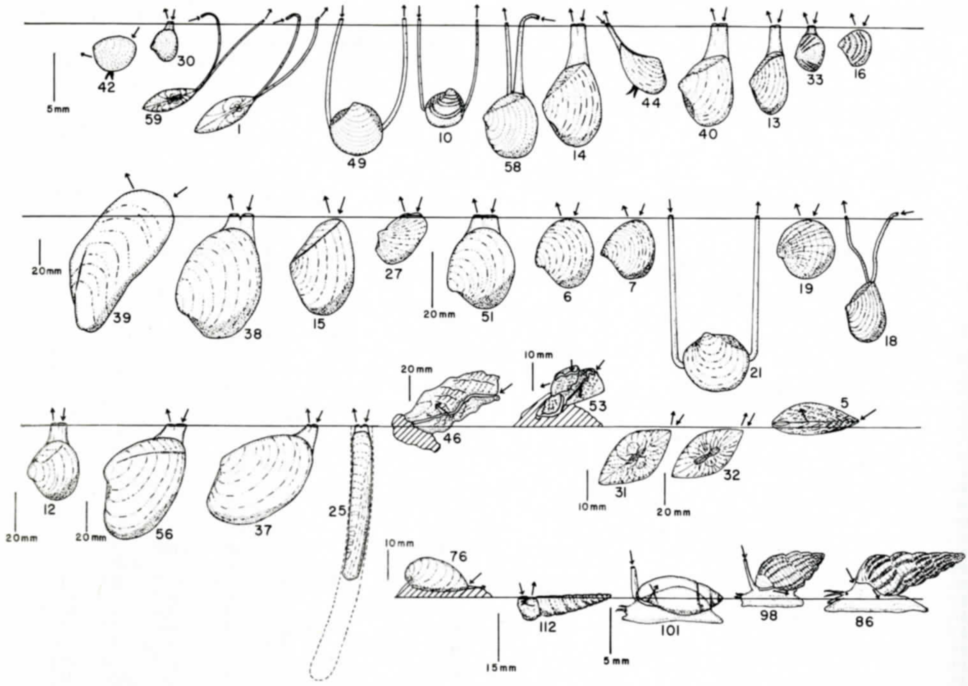

Figure 3. Inferred modes of life for molluscan species making up trophic nuclei. Arrows indicate inhalent and exhalent currents. Cross-hatched areas indicate solid substratum. Scales apply for species to right; if none is given use first scale to left of species. Numbers refer to Table 1.

COMMUNITY STRUCTURE

In the following discussion communities are analyzed with respect to the modes of life and trophic relationships of constituent species. The modes of life are based on field observation and reference to similar extant species. The works of Stanley (1968, 1970) and Fretter and Graham (1962) were particularly valuable in determining possible modes of life and feeding types for molluscan species. A more complete bibliography is given in Bailey (1973). Table 1 gives the modes of life and feeding types for all molluscan species considered in this study. Figure 3 shows the reconstructed modes of life for the 37 numerically dominant species that make up the trophic nuclei for communities I - VIII.

Trophic analysis allows the interpretation of one attribute of a community based on a consideration of major feeding groups. Trophic groupings may be either homogeneous, containing all suspension feeders or all deposit feeders, or heterogeneous, containing mixtures of

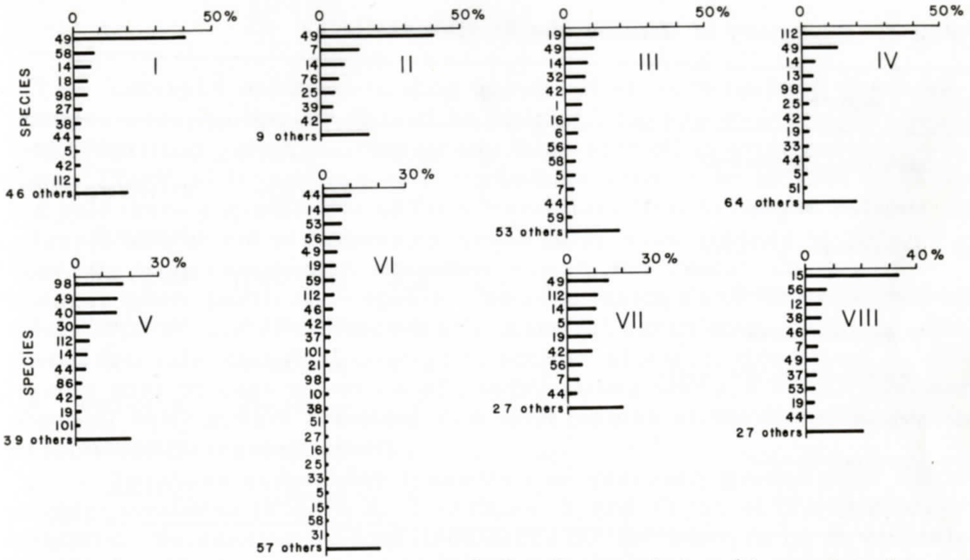

Figure 4. Species occurrences and abundances in trophic nuclei of communities I - VIII. Species are indicated by numbers assigned in Table 1. Species abundance is given as percentage of total individuals in community.

suspension feeders and deposit feeders, with the most abundant species making up the trophic nucleus (Rhoads and others, 1972). In this study the trophic nuclei (Figure 4) are considered to be those numerically dominant species making up 80 percent of the total sample. The definition distorts the original biomass relationships by placing more emphasis of the smaller and usually numerically abundant species.

The trophic relationsips of the communities are summarized in Table 2. Trophic nuclei (Figure 4) are all heterogeneous with the exception of community IX, which is dominated by an inferred, infaunal deposit feeding organism. Most communities are dominated by shallow infaunal, suspension feeding bivalves. A group of small bivalves (Parvilucina crenulata, Corbula inequalis, Nuculana acuta, Syndosmya aequalis, Tellina declivis, and Nucula proxima) are abundant in 8 communities. The first two are suspension feeders, the latter four are deposit feeders. Their ubiquity suggests that appropriate substrata and food resources were present in most of the environments included in this study. Deposit feeders utilize various types of food contained within the sediment. Fine clayey sediments generally contain significant amounts of organic material and are thus often inhabited by deposit feeding populations (Sanders, 1958). Deposit feeders Nuculana acuta, Nucula proxima, Syndosmya aequalis, and Tellina declivis may represent temporally stable populations that persist as long as the food resource within the sediment is adequate. The sediments of practically

Table 2. Summary of Community Attributes.

	Community	A	B	C	D	E	F
I	*Mercenaria-Septastrea**	57	2	10.0	49/11/28/12	49/7/39/5	3
II	*Modiolus-Cumingia*	16	4	6.1	69/31/0/0	62/19/19/0	2
III	*Argopecten-Glycymeris*	67	2	13.6	58/9/21/12	50/6/39/5	7
IV	*Turritella-Panopea*	76	3	16.0	52/12/25/11	50/12/38/0	5
V	*Nassarius-Mulinia*	50	3	5.0	58/14/22/6	56/10/34/0	4
VI	*Crassatella-Macrocallista*	82	10	14.8	54/9/27/10	49/11/39/1	6
VII	*Argopecten-Mellita**	21	2	3.3	66/24/10/0	80/10/10/0	8
VIII	*Corbicula-Rangia*	38	2	5.0	79/18/3/0	71/18/11/0	9
IX	Polychaete (?)	?	0	0	Deposit	Infaunal	1

A) Diversity; total number molluscan species
B) Number of samples
C) Total volume sampled in liters (fossils + matrix)
D) Proportions of feeding types (percent)
Suspension/Deposit/Scavenger - Carnivores/Others
E) Modes of life (percent)
Shallow infaunal/Deep infaunal/Epifaunal/Others
F) Ranking based on the probable abundance of allochthonous individuals (see text)

* *Septastrea* - coral
* *Mellita* - echinoid

all samples contained between 10 and 60 percent clay and silt that was probably associated with considerable organic matter. This deposit food resource may have acted as a buffer against short term food shortages and provided a predictable food source for the deposit feeders (Levinton, 1972). Community IV is dominated by a filter feeding gastropod, Turritella. Epifaunal suspension feeders are scarce with Ostrea sculpturata, Argopecten eboreus, and Plicatula marginata being the most important. The coral, Septastrea, an important member of community I, is a high level feeding carnivore. Large, carnivorous gastropods are present, but none are dominant in the trophic nuclei (Table 1). Three smaller carnivorous and scavenging gastropods (Nassarius chowanensis, Olivella mutica, Epitonium cf. E. pratti) are present in the trophic nuclei (Figure 4). The scarcity of the larger carnivorous gastropods such as Busycon maximum, Polinices duplicatus, and Lunatia heros is characteristic of their higher positions in the trophic structure.

COMMUNITY TRANSITIONS

Lateral transitions among communities were mapped where exposures were continuous enough to provide adequate stratigraphic control (Figure 2). Vertical transitions were studied in stratigraphic sections. Vertical transitions of communities seem to be related to shifting paleoenvironments that cause concomitant faunal changes as species migrate into or out of favored environments. This process is distinctly separate from community evolution where the faunal composition changes when particular species become extinct and are replaced by newly evolved and often functionally identical organisms. It is also different from the classical concept of ecological succession where a community goes through a series of modifications within a single constant physical environment resulting in a final mature stable faunal or floral association (Margalef, 1968).

Yorktown community transition is generally gradational, but at several localities (Figure 2, localities 2 and 8) faunal changes occur abruptly. Succeeding paleoenvironments did not seem to be so radically different that a completely new set of species was introduced; however, the positions of the abundant species in the trophic nuclei were significantly reordered. The community sequence at locality 2 will be used to illustrate the general nature of the vertical transition of communities.

At locality 2, communities III (Argopecten - Glycymeris) and I (Mercenaria - Septastrea) are exposed in the lowest 0.6 m of the outcrop (Figure 2). Septastrea started to grow on a shell covered bottom; however, the colonies remained small and no coral thicket developed. These communities grade abruptly into a sparsely fossiliferous, slightly coarser sand that contains community VII (Argopecten - Mellita). During this transition, faunal diversity and density (no. of specimens/liter of sample) drops and the sand dollar, Mellita aclinensis is introduced. Higher in the section, a thick unit of thinly laminated, burrowed, fine sand and clay contains thin shell beds and very sparse fossil molds. During deposition of the clayey interval, very few molluscan species could survive in the muddy bottom sediments. Because of low faunal diversity and poor preservation, the fossil assemblage in this unit was not assigned to a community. Community VIII (Corbicula - Rangia) occurs abruptly in the upper 1 m of the outcrop. This community contains 38 species, with only two unique species, Corbicula densata and Rangia clathrodonta. The above changes in faunal content seem to indicate significant environmental changes during the deposition of the vertical sequence. Hazel (1971a) suggested that the Pliocene deposits along the Chowan River record part of a regression which probably started in middle Yorktown time. The sequence discussed above appears to document a regressive phase of the late Pliocene sea. The vertical sequence is interpreted as representing an approximately eastward migration of the following series of environments: (1) outer shallow shelf; community

III, I, (2) inner shallow shelf; community VII, (3) lagoon or sound; laminated sparsely fossiliferous clay, and (4) sound, lagoon, or inlet; community VIII.

Bird (1970) considered some aspects of level-bottom community transition in the marine shallow shelf and estuarine environments around Beaufort, North Carolina. He noted that the transition between two communities is marked by a gradual shift in species abundances which creates a gradational boundary between the communities (Bird, 1970). The Holocene communities Bird studied show a gradual turnover of species paralleling a marine to estuarine salinity gradient. The vertical section at locality 2 also seems to reflect gradually changing environments and associated faunal turnover.

SUMMARY AND CONCLUSIONS

(1) This study documents the presence of 9 paleocommunities in Neogene deposits along the Chowan River. The communities are recognized primarily on the basis of molluscan species. Many species occur in more than one community, but a particular group of species is numerically dominant in each community. Bird (1970) observed that changes in community composition occurred by shifts in the dominance rankings of the most abundant species rather than by total changes in species composition. The Pliocene fauna discussed in this study also exhibits reordering of dominant species among the different paleocommunities.

(2) That the communities were migrating in response to changing environmental patterns is evidenced by the analysis of vertical sequences of sediments, sedimentary structures, and molluscan assemblages. Lateral community transition should be preserved in the stratigraphic record as a vertical faunal succession. Theoretically the vertical succession should be continuous, but patchiness of communities and reworking of previously deposited sediments and faunas tends to create a discontinuous sequence. At one locality a regressive sequence of environments, from marine to estuarine was inhabited by a discontinuous, but logical, series of molluscan communities.

(3) Consideration of feeding groups allowed the interpretation of one attribute of the communities. With the exception of the burrow community, all trophic nuclei were heterogeneous, with shallow infaunal, suspension feeding bivalves dominant. The fact that most of the bivalve species fed at one level, the substratum-water interface, indicates that vertical separation of various suspension feeding bivalves was not a primary mechanism of avoiding feeding competition (Walker, 1972). Other possible mechanisms might be differing food particles size, or differing food preferences among various suspension feeders. The presence of deposit feeders in all communities suggests that a predictable food resource was present in the sediment.

(4) Most of the extant species and genera considered in this study are typically found on shallow to deep, level-bottom, shelf environments, and in marginal marine environments, such as lagoons or bays. The high faunal diversity and the associated silty and clayey fine sands of communities I (Mercenaria - Septastrea), III (Argopecten - Glycymeris), IV (Turritella - Panopea), and VI (Crassatella - Macrocallista) are characteristic of Recent communities found in shallow to moderately deep shelf environments. Community VII (Argopecten - Mellita) is found in well sorted medium sands, which, together with Mellita, indicate a very shallow shelf environment. The very muddy sands containing community II (Modiolus - Cumingia) and community V (Nassarius - Mulinia) are typical of lagoon and bay environments. The polychaete (?) community (IX) may have existed in a subtidal lagoon, bay, or nearshore shelf environment. The abraded shell fragments and relatively coarse matrix (silty medium to coarse sand) associated with two brackish water genera, Corbicula and Rangia, (community VIII) strongly suggest a marginal marine environment, perhaps a lagoon, sound, or estuary where faunal mixing occurred.

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THE AGE OF THE ALCOVY RIVER SWAMPS:

A DISCUSSION

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I noted with considerable interest the recent article by Staheli, Ogren and Wharton (1974) wherein they purport to show that the Alcovy River swamps were caused by natural processes rather than accelerated soil erosion. Unfortunately, their sweeping conclusions are not supported by their scant data. Briefly, I note the following points:

1. The reader is not given the exact site and situation of the C-14 samples. One must know:

A. Were the samples taken away from the channels near the upland? As I noted in my article (Trimble, 1970, p. 138), most sediment deposition from coarse Piedmont soils was in and along the channel, raising the stream level and inundating the bottoms. Often, bottomland quite distant from the stream was covered only by a thin layer of silt and clay. Swamps are created by rising water levels, not necessarily by aggrading flood plains remote from the stream. Note the enclosed portrayal of Piedmont stream and valley evolution, particularly that of the 5th order valley (Figure 1). Staheli et al. state (p. 103) that they took their samples in the swamp. Thus, they have not measured stream channel or levee aggradation, nor the rise of water level by whatever means. I do not doubt that many of these swamps have been formed on quite thin deposits covering the old flood plain soil.

B. Were the samples taken from an old low terrace buried, or nearly so, by modern deposition? In several years of field work along streams, I have seen terraces flush, or nearly so, with flood plains which had only recently aggraded to the level of the terrace.

The two possibilities above make it clear that anyone could, should he want to, find flood plain sites having little modern deposition. The discriminating reader would want to see samples taken across several flood plain cross-sections, and especially at the sites which I specifically mention in my study. The presentation of such samples should include, as a minimum requirement, cross-sectional profiles showing sample sites. Also, precise site descriptions (with witness points) should be given so that the exact sample site could be recovered by other scientists for further study.

2. The second point involves the "organic debris" for the samples. Was it resident at the sample sites, or washed in? If washed in,

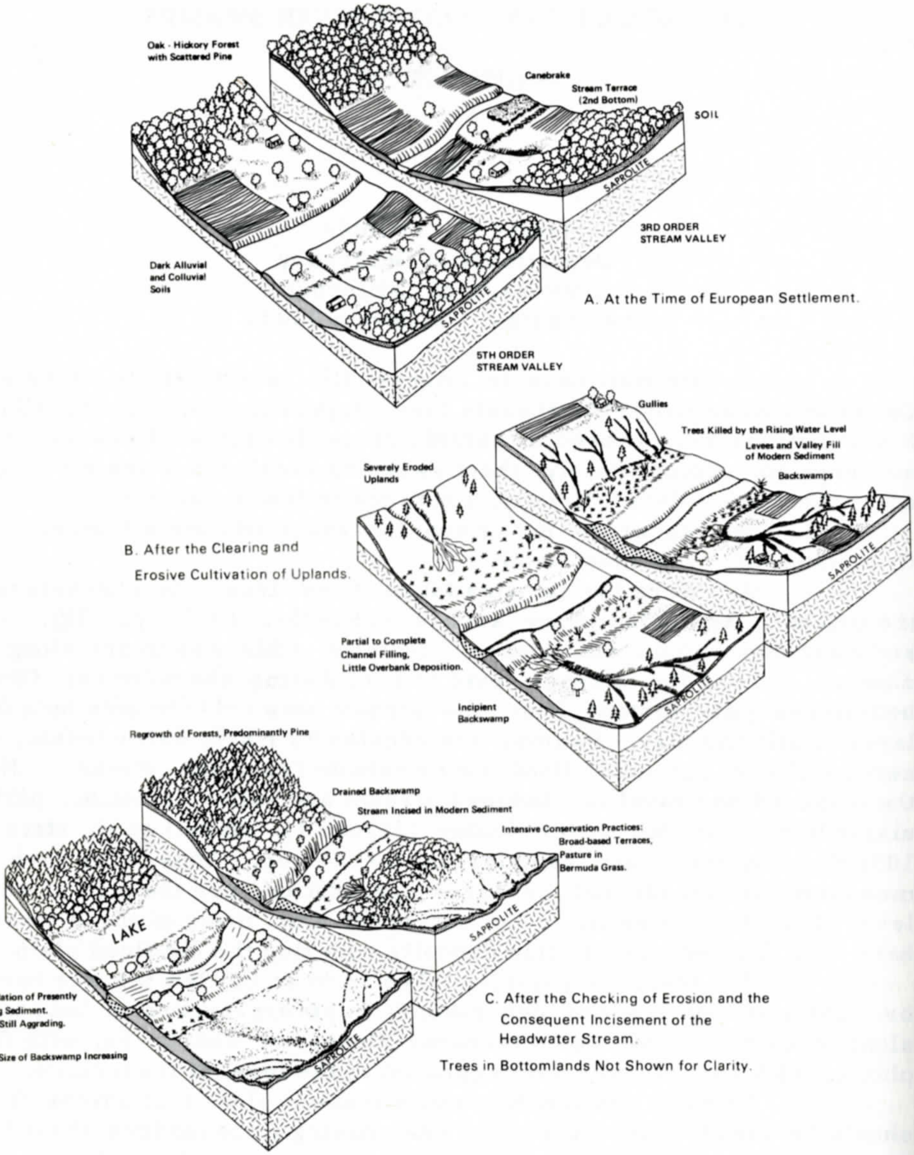

Figure 1. Generalized evolution of the Piedmont landscape, 1700-1970 (from Trimble, 1974).

when? In my article (1970, p. 135-136), the recent burial of much organic material is noted. The chance of a sample being exotic is one which always haunts C-14 investigators. Thus, this possibility will have to be precluded to make the C-14 dates valid for interpretation.

3. If these swamps are pre-modern, where are the deep organic deposits that would have been formed? That is, the heavy vegetative

biomass production should have been preserved in the wet, probably anaerobic, conditions of the swamp. Indeed, the water now stands several feet deep in some of these swamps. It may be instructive to note that the Coastal Plain swamps, which no one doubts existing before European settlement, are replete with histosols.

4. Staheli et al. conclude that "no abnormally large amounts of erosional debris have entered the Alcovy drainage basin since the beginning of agricultural activity in this area" (p. 105). However, two different studies have shown that the Lloyd Shoals watershed, of which the Alcovy basin is a large part, lost almost seven inches of soil between 1814 and about 1940. This amounts to about 465,000 acre-feet of material (Montgomery, 1940; Trimble, 1975A). Even now, the healed scars of this erosion are apparent to anyone who recognizes a soil profile, or the lack of one.

Assuming a uniform loss over time, about 19 percent of the material was transported as far as the present Lloyd Shoals reservoir. This means that about 390,000 acre-feet of erosional debris have to be accounted for as colluvial and alluvial deposition in a watershed having a total area of 899,000 acres, and a depositional area of 66,000 acres. If Staheli et al. are correct in their conclusions, they now owe us an explanation of how 390,000 acre-feet of erosional debris has presumably disappeared.

Many studies have documented the filling of Piedmont streams and swamping of Piedmont valleys. (For example, see the bibliography in Trimble, 1974, p. 166-180). Streams adjacent to the Alcovy have filled, some as deep as 18-20 feet with concomitant swamping. Moreover, many streams of the humid United States have undergone modern sedimentation similar to that of the Alcovy River (Trimble, 1975B). Yet, Staheli et al. give us to understand that the Alcovy River, with a comparatively low gradient, has miraculously escaped this sedimentation.

5. Most importantly, the authors ignored the large body of evidence which I introduced. Certainly their evidence can in no way justify their presumptuous conclusions. To begin to justify their conclusions, all of my evidence would first have to be disproved. Then, any C-14 evidence introduced would have to meet the criteria already outlined. Additional evidence from Staheli, et al. would be most desirable. I am especially surprised at the lack of botanical evidence. For example, perhaps they can explain the dead trees of diverse mesophytic species still standing in some of those swamps with their root crowns inundated (e. g. road crossing of Alcovy River and Beaverdam Creek northeast of Between, Georgia). I am curious to know how mesophytic trees took root beneath the water surface, but died as mature trees.

Finally, I note with interest that one core (c) with two dates. Assuming the mean dates to be correct, the average rate of aggradation for the upper 1.6 feet is about twice that of the next 9.6 feet. If the most recent dates are accepted, the disparity becomes considerably greater. This point was not noted in their discussion. But again, deposition in the back swamps is not necessarily indicative of channel filling, levee building, and rising water levels.

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AGE OF SWAMPS IN THE ALCOVY RIVER DRAINAGE BASIN: A REPLY

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It is the intent of this reply to answer the questions raised by Trimble (1976). We gratefully acknowledge the Trimble (1977) discussion which showed a need to more accurately locate C^{14} sampling localities discussed in Staheli et al. (1974). We hope Table 1, showing latitudes, longitudes, locality descriptions, and descriptions of organic debris sampled at C^{14} sampling localities, will clear up this problem. These localities were chosen: (1) because they were within an area depicted by swamp symbols on 7 1/2 minute topographic maps of the region; (2) because the swamps were easily accessible for sampling; and (3) because these localities represent as many varied morphological regions within the areas depicted by swamp symbols on 7 1/2 minute topographic maps as our limited funding would permit sampling.

When using C^{14} dating, certain problems and complications may arise, such as, problems of sampling, dating of reworked rather than original materials or samples being affected by groundwater leakage. Despite the probability of such errors, all dated horizons from widely spaced localities (Staheli et al., 1974) produced C^{14} dates that predated the arrival of European-style agriculture on the Piedmont. In the face of such consistent dates, therefore, it would be unwise to suggest the probability that all dated horizons are in error. Instead, the very consistency of such old dates (pre-European settlement) suggests just the opposite. Further, the probability that this material was not reworked is enhanced by the very consistency of sedimentation rates (Table 2) relative to the sample dates (Table 1). Finally, it seems unlikely that all of the kinds of organic debris sampled (wood, twigs, and other vegetable matter) shown on Table 1 would lend themselves equally to reworking.

Table 1. Additional Data for C^{14} Sampling Localities in the Alcovy River Drainage System. After Staheli et al. (1974).

Sample	Latitude	Longitude	Location	Type of Organic Matter
A	33°42'28''N	83°46'27''W	Off-levee area	Vegetal matter
B	33°40'03''N	83°46'34''W	Back-levee	Woody matter, Twigs (peat)
C* *At Depth (1.6 ft.)	33°36'56''N	83°48'02''W	Levee, 50 ft. from river	Woody matter, Twigs (peat)
C** **At Depth (10.9 ft.)	33°36'56''N	83°48'02''W	Levee, 50 ft. from river	Wood
D	33°35'28''N	83°48'32''W	Old levee	Wood
E	33°35'25''N	83°48'35''W	Oxbow with histosol	Marsh sediment, sediment fines, vegetal matter

Table 2. Rates of Sedimentation for the Alcovy River Drainage System Calculated from Depth of Dated Horizon to Surface. Data after Staheli et al. (1974).

Age in Years B. P.	Depth in Feet (meters)	Rate of Sedimentation Feet (meters) per 100 years	Location
190	1.6 (.49)	.84 (.25)	C
425	2.3 (.70)	.54 (.16)	E
490	4.0 (1.22)	.81 (.24)	B
670	3.5 (1.07)	.52 (.15)	A
1850	10.9 (3.32)	.56 (.17)*	C
8725	13.3 (4.05)	.15 (.04)	E

*Calculated between lower and upper dated horizons.

Few would argue that soils developing on different geologic and geographic areas are identical. Why then should one expect swamps or histosols to develop identically on regions that differ as widely as do the Coastal Plain and Piedmont regions? Further, swamps may contain high areas such as old levees that dry before lower off-levee and oxbow areas, thus forming different soils and types of vegetation within a swamp. In such cases, histosols are more likely to develop on the lower areas on floodplains. Periodic drying on the higher levee areas, however, would hinder histosol development. Prolonged periods of wet or dry conditions would affect the establishment or destruction of mesic vegetation on higher or lower areas within swamps. Thus, the areas depicted as swamp on 7 1/2 minute topographic maps do not contain the same soil types throughout, nor do these areas have to develop histosols. The fact that most of these sampling localities (Table 1) are not in histosols, yet are within areas depicted by swamp symbols on topographic maps, supports the probability that these localities are from levee and not off-levee areas.

Trimble (1975) estimates gross erosion across the Piedmont at 95 mm per 100 years. He estimates only 5 percent of this eroded material is being exported. The remainder is being trapped behind dams or is still in the system deposited as colluvium or alluvium as deep as 6 meters in small and medium size streams. The Alcovy River is a small to medium size river flowing through a rural area that was previously heavily farmed, and there are no man-made reservoirs upstream from dated localities (Table 1) to impound sediment. Yet no accumulation rates shown on Table 2 are greater than 0.25 meter per 100 years and half the locations have sedimentation rates between 0.15 and 0.17 meter per 100 years. These deposition rates are larger than the upland erosion rates reported by Trimble (1975), but the area of deposition is much smaller than the area of erosion. Therefore, we consider these sedimentation rates to be low. Further, different sedimentation rates are not unexpected at different times or at different locations in the depositional regimes on floodplains. Rates may vary because of local changes in river gradient, upland slope, rock type, or on- or off-levee sampling as suggested by Trimble (1977).

We do not suggest that there are no localities in the Alcovy system with abnormally high rates of sedimentation. We believe such areas, however, were affected by local conditions generated by variations in local rock type, road construction, or some abnormal circumstance. In fact, the 1976 Geologic Map of Georgia shows the Alcovy River system underlain by a variety of rocks including areas of undifferentiated granite gneiss. This gneiss could, under the right set of circumstances, be capable of generating considerable quartz and other clastic debris. However, the fact that low or normal sediment rates are found at sampling localities (Table 2) strengthens the argument that accelerated rates are a local phenomenon. Otherwise, under regional aggradation would one not expect to find some of the levee sampling localities (Table 2) showing abormally high rates of sedimentation? Trimble (1970, p. 138) shows levee areas receiving maximum sedimentation.

The low rates of sedimentation shown on Table 2 might attest to one or all of the following: (1) that the up to 6 meters of sediment fill in the rivers of this region (Trimble, 1975) has already moved past the dated localities on the Alcovy River; (2) that the sediment influx has not yet left the third or fourth order streams upstream from dated localities; (3) that Trimble's (1975) rate of erosion (95 mm per 100 years) is too high for this region; (4) that the larger-size fraction of the eroded material is remaining on the peripheral areas of the larger floodplains as colluvium and alluvial materials and has not yet reached the major streams; (5) that the majority of the eroded saprolite being transported is clay size and is not being trapped by the swamps but stays in suspension; (6) that the major rock types on which the Alcovy River flows (biotitic gneiss, mica schist, and amphibolite - Geologic Map of Georgia, 1976) produces weathered clay- and colloidal-size sediment and little quartz or clastic debris.

We believe the low rates of sedimentation in the Alcovy River swamps as shown on Table 2 do not necessarily conflict with geologic data showing erosion on the uplands of the Georgia Piedmont. We feel that any one or any combination of the above six factors could account for the low rates of sedimentation shown on Table 2. Thus, we argue the validity of the conclusions presented in Staheli et al. (1974).

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